NASA Technical Memorandum 100 473

# Johnson Space Center
# Research and Technology
## Annual Report 1988

National Aeronautics and Space Administration

ORIGINAL PAGE IS OF POOR QUALITY

(NASA-TM-100473) RESEARCH AND TECHNOLOGY OF THE LYNDON JOHNSON SPACE CENTER Annual Report, 1988 (NASA) 169 p CSCL 05D
N89-20918
Unclas
G3/99 0200247

NASA Technical Memorandum 100 473

Johnson Space Center

# Research and Technology

Annual Report 1988

March 1989

Prepared by
New Initiatives Office
Lyndon B. Johnson Space Center
Houston, Texas

# Preface

The Johnson Space Center (JSC) Research and Technology Report is prepared annually to highlight the Center research and technology activities during the past year. Beginning with this edition, the responsibility for the report will be assumed by the New Initiatives Office of JSC.

The New Initiatives Office has been established to place explicit emphasis on the research activities of JSC. Although JSC is a NASA development center, it is conducting significant space-related research. As the nation and the local community become more concerned about the potential commercial aspects of space, it becomes imperative from a development, operations, and commercial perspective to promulgate the results of research activities. The intent of this report is to inform Research and Technology Program managers and their constituents of significant accomplishments that promise practical and beneficial program applications. While not inclusive of all R&T tasks, the scope of the report has been significantly expanded and represents a comprehensive summary of JSC's activities during 1988.

The development of this report represents a coordinated effort with JSC line organizations, most notably the Administration Directorate, Space and Life Sciences Directorate, and Engineering Directorate. Their efforts as well as those of the individual authors are commended and are recognized as essential contributions to this report. Personnel listed below have written the section summaries and coordinated the technical inputs for their respective sections of the report. Detailed questions may be directed to them or to the principal investigators listed in the Index.

A. E. Morrey/Code BI/IA    Overall Coordination
(713) 282-1866

C. S. Alton/Code EA    Space System Technology
(713) 483-0495

F. Vilas/Code SN    Solar System Sciences
(713) 483-5056

E. M. Crum/Code IC    Space Transportation Technology
(713) 282-1908

J. L. Homick/Code SD    Medical Sciences
(713) 483-7108

William J. Huffstetler
Manager, New Initiatives Office

PRECEDING PAGE BLANK NOT FILMED

# Contents



PRECEDING PAGE BLANK NOT FILMED

# Space Systems Technology

## Summary

## Space System Technology

### Introduction

The Space Systems Technology section is composed of six technical disciplines including Life Support, Extravehicular Activity, Human Factors, Materials and Structures, Space Data and Communications, and Space Flight Experiments. These studies encompass the bulk of the research and technology efforts currently underway at JSC. Good progress has been achieved in preparing the way for the Space Station Freedom program, orbital activities, and interplanetary missions, all of which are represented in the discussions presented below.

### Life Support

Life support system research is currently directed toward long-duration manned space missions in which regenerable life support processes will be utilized. One such process is the recovery, purification, and recycling of waste water for human consumption and hygiene use. The monitoring of purified waste water is critical to assure the safety and well-being of the crew. In a breadboard experiment conducted at JSC, an ultraviolet radiation source was combined with an infrared analyzer to first oxidize organic impurities and then analyze the resulting carbon dioxide to provide a highly sensitive measurement of the amount of organic impurity present. Such monitoring techniques constitute an advance in the state-of-the-art technology and support the goal of long-duration missions.

In another recycling technique, carbon dioxide from waste breathing air along with water vapor has been electrolyzed directly into oxygen resulting in full recovery of oxygen from metabolic carbon dioxide. The advantage of the new technique is in its low operational voltage.

### Human Factors

Astronauts are faced with an increasingly complex and diverse array of spacecraft, missions, and operating environments, including near-term and future plans for orbital and planetary operations and exploration. Environmental factors, (e.g., lighting, gravity level) and supporting resources, (e.g., food, information, tools) will have major implications on crew performance, capabilities, and limitations, as well as the degree to which mission success may be achieved. Research and technology at JSC in human factors has three major thrusts: (1) quantify human capabilities and limitations (shirt-sleeved and suited) in space and planetary surface operation environments; (2) understand and optimize human interfaces and interactions with spacecraft systems, crew equipment, and supporting resources in operational environments; and (3) identify and maintain standards, requirements, and guidelines which serve the NASA community, concerning integration of humans into manned space systems.

Human factors research at JSC reflects the multi-faceted nature of the discipline. As examples, current research topics detailed in the following paragraphs address sophisticated computerized human modeling, human strength and motion investigations, human-computer interactions, human interactions with telerobotic systems, and development of state-of-the-art crew equipment and manned systems hardware. Crew safety and productivity are enhanced through this research, which not only increases our understanding about humans in space on a practical level but also ensures technology transfer at a significant level to the NSTS and Space Station Freedom Programs.

### Materials and Structures

Several advances in materials and structures technology were made at JSC in 1988. A high-energy atomic oxygen source was developed that is capable of generating a beam of oxygen which can be used in the testing of potential Space Station materials. This is necessary because atomic oxygen present at low Earth orbit altitudes has been found to seriously degrade the surface of many engineering materials. With a high-energy oxygen beam, sample materials can be subjected to a far more intense exposure to atomic oxygen than that present in orbit. This permits long-term exposure effects such as would be sustained over a 15-to-30 year Space Station lifetime, to be studied in reasonable test run times on the ground.

Tests run with the new device have already had significant results -- some materials have been found to be inappropriate, others to be acceptable for Space Station use. Oxygen-protective coating performance has been evaluated and one unexpected, and as yet unexplained, coating failure mechanism has been discovered. Technology spin-off's have also arisen that promise to enhance the production of high-temperature superconductors and gallium arsenide chips.

In the structures discipline, a new technique is being developed to permit in-flight structural testing of large, long-duration mission spacecraft. The method uses comparisons between an analytical database of spacecraft frequencies (what the structure should be) and real-time measured frequencies (what the structure now is) to spot fatigued or failed elements of the vehicle structure. This could improve the safety and reliability of the vehicle or of the Space Station by permitting the guidance and control system to be reconfigured to limit operations that would jeopardize the structure.

In another area of structural design, a mechanism has been designed, built, and tested that will enhance berthing operations in orbit. It is a latch with extra-long reach to accommodate the limits of precision for Remote Manipulator System (RMS) positioning of payloads or space station modules during berthing operations. Such a latch mechanism would be mounted around the docking port of the payload or module so that it could be activated remotely when the payload or module is placed within four inches of its attach point on another module. The need for such an extra-reach latch has been recognized since the definition phase of the space station program.

## Space Data & Communications

Laser technology is at the forefront of space data and communications research, especially in target tracking and optical communications. At JSC, engineers are working on laser improvements that will enhance lidar (LIght raDAR -- the use of reflected laser light to obtain information about a target) for range/range rate finding (distance and speed) and on a laser reflector made of multiple materials that will identify the orientation (pitch, roll, and yaw) of a target vehicle.

Another group of engineers is investigating the use of lidar for the detection and tracking of orbital debris -- one of the most significant threats to the safety of the Space Station. Other improvements in laser technology, such as a tuning device that varies the wavelength and a scanning device that will spread a beam across a field of view at high speed, promise to enhance target tracking, free-space optical communications and long-range secure communications.

Space Station communications constitute an area of intensive effort at JSC with breadboard development and analyses being conducted on several fronts. Breadboard development efforts include research into the use of fiber optic components to handle signal transfer between space station node equipment and the outside antenna-mounted equipment, infrared components to provide voice and data communication channels, and a Ku-band antenna built with microwave integrated circuitry to communicate with vehicles from 100 m to 37 km out.

Analyses of coverage and obscuration patterns have been performed on various configurations of S- and L-band antennas on the Crew Emergency Rescue Vehicle. In addition, work has been initiated on establishing specifications for channel separation and other factors on the subsystem that provides video, audio, and data signals to users in the vicinity of the station such as "free flyers", the Orbital Maneuvering Vehicle and the Flight Telerobotic Servicer.

Communications systems have become so complex that computer simulation is often performed for proposed system designs. JSC is sponsoring the development of new efficient simulation algorithms to facilitate communication engineers in their analysis and design of complicated systems. In 1988, this effort demonstrated the incorporation of an expert support system to streamline modeling procedures.

In addition to communications systems, other space systems such as guidance and control, thermal control, and computer networks also benefit from incorporated expert systems. One activity at JSC involves integrating TEXSYS (Thermal Expert System), a set of software that will be used in developing a possible Space Station active thermal control system. One of the most promising areas for the use of expert systems or artificial intelligence is the monitoring, diagnosis and management of system faults and failures. During FY88, generic modeling and simulation software was designed that enables the development of a capability within an expert system to mimic human analysis of system behavior, i.e., to use partial information to identify likely causes of system problems and provide reasonable responses (tests or control actions). Future plans call for further automation of this process and its expansion to cover real-time management of unanticipated failures.

Other generic advancements are being made in data processing through a partnership between JSC and a local university. Engineers are developing new ways to improve software productivity such as software reuse, standardization of operating system interface sets, and the integration of expert systems with more traditional software components.

In the field of data processing, one of the most powerful techniques to evolve in recent years is computational fluid dynamics (CFD) which is capable of providing numerical simulation of the aerodynamic flow of air around a flight vehicle. This technique is being used at JSC to develop hypersonic technology to both support the space shuttle program in assessing aerodynamic loads and heating during entry and to prepare for the advent of lifting-body type vehicles.

## Space Flight Experiments

JSC involvement in space flight experiments in 1988 centered on four areas - Space Shuttle onboard communications, laser-assisted docking, the handling of cryogenic fluids in orbit, and aeroassisted deorbit techniques. The work on Space Shuttle communications resulted in the completion of one flight demonstration (on STS-26), while the other efforts were all in support of future flight experiments. Additional communication system efforts supported the Optical Communication Through the Space Shuttle Window (OCTW) experiment. Laser-assisted docking activities supported the Laser Docking Sensor (LDS) experiment, cryogenic fluids work was in support of the Cryogenic On-Orbit Liquid Depot - Storage, Acquisition, Transfer (COLDSAT) experiment, and aeroassist work supported the Aeroassisted Flight Experiment (AFE).

The STS-26 demonstration was an infrared crew-worn communications device which provided better coverage and voice transmissions than the previous radio frequency system. It also provided secure communications by using selected infrared wavelengths that would not pass through the Orbiter windows. The upcoming OCTW experiment will test a new fiber optic system that would be used for communication of data and control signals between payloads in the payload bay and the payload specialist on the aft flight deck.

The LDS experiment is being developed for flight on the Space Shuttle by 1993. It will demonstrate the use of a laser system to more accurately determine relative spacecraft location, orientation, and motion for docking, stationkeeping, and berthing operations. The technology will enable the future implementation of automated docking. In 1988, preparations for this experiment included the purchase of subsystems and ground support equipment and the development of integration

requirements. In addition, an effort was initiated to develop an intelligent controller (expert system combined with display capabilities) for the LDS experiment. It will function in adaptive sensor control and pilot decision support. This reusable (and therefore cost-effective) software will be tested by astronauts on a Space Shuttle computer to determine user friendliness and utility.

Support work is also being conducted for the COLDSAT flight experiment to be flown on the Space Shuttle or on an Expendable Launch Vehicle (ELV) The JSC project has developed and tested a method to determine how much cryogenic fluid (liquid hydrogen or liquid oxygen) is present in a storage tank in zero g. The problem in zero g is that liquids may form into multiple bubbles and/or line the container walls making accurate gaging difficult. The zero g fluid quantity gaging method being investigated is the "compressibility" method. This consists of slightly compressing a stored mass of liquid by repeatedly pushing on a diaphragm mounted in the wall of the container. The pressure of the gas above the liquid (or perhaps adjacent to it in zero g) is simultaneously measured. Since the change in container volume was known (amount of diaphragm push), the resultant change in gas pressure can be used to calculate the gas volume. By subtracting this from the container volume, the volume of liquid is thereby determined. The technique will work with various liquid orientations and fill levels and in the presence of bubbles, pressurant gasses, and thermal layering. It is applicable to both cryogenic and room temperature fluids in orbital vehicles and storage tanks.

As the space program expands human operations beyond low Earth orbit, alternative navigation techniques for orbital transfer, interplanetary mission returns and reentry from high altitude orbits will be required. One technique currently receiving intense interest is aeroassisted orbital transfer. Plans are underway for an Aeroassisted Orbital Transfer Vehicle (AOTV) and for a preliminary experimental flight vehicle, the AFE. The AFE will simulate the atmospheric flight phase of an AOTV returning from geosynchronous orbit. It will skim through the upper levels of the atmosphere and target for a preset orbit suitable for Orbiter retrieval. JSC is supporting AFE not only with the development of hardware and experiments for the mission itself but also in several research and technology projects.

In one of these projects, a numerical flow simulation was used to support the design of onboard lee side flow experiments on AFE. Another project involves a set of instruments called the Base Flow and Heating Experiment. This experiment will be onboard AFE during its flight to measure temperature, pressure, and electron and ion concentrations at the surface of the vehicle. Video cameras will film the radiating gas in the airflow around the base region (aft end) of the vehicle and in its wake, to learn more about the structure of the airflow.

ORIGINAL PAGE IS
OF POOR QUALITY

# Space Systems Techology

## Significant Tasks

PRECEDING PAGE BLANK NOT FILMED

PAGE 6 INTENTIONALLY BLANK

## Reagentless Organic Carbon Monitor of Spacecraft Reclaimed Waters

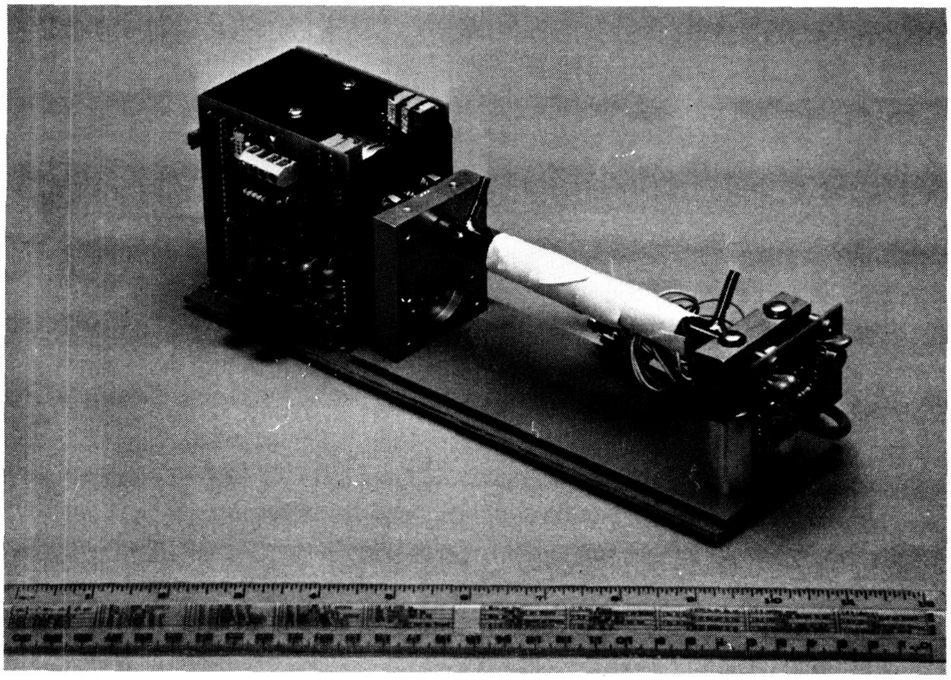
**PI: Charles E. Verostko/EC5**
**Reference SST 1**

Manned planetary missions will require that waste waters be purified for human consumption and hygienic use. The recovered water must be monitored for organic impurity content to assure that the water is safe for reuse and the reclamation process is providing reliable performance. The development of a breadboard reagentless organic impurity content monitor provides a technology base for the future development of highly sensitive and reliable monitoring instrumentation with the minimum power, size, and weight required for closed life support systems.

The breadboard monitor can detect organic carbon impurity content in water at levels <500 ppb. The concept consists of utilizing ultraviolet radiation at a temperature of 95 degrees centigrade to oxidize the organic impurity to $CO_2$ with subsequent measurement by a non-dispersive infrared (IR) analyzer technique. The UV radiation source, consisting of a single centerline frequency of 184 nm at a power of 2 mW/cm, was selected to obtain maximum oxidation efficiency. A quartz sheath encloses the UV source in the reclaimed water to obtain maximum UV transmittance for optimum oxidation. Extensive testing with simulated reclaimed waters has shown that the design goal of stoichiometric recovery was attained without reagent.

The IR analyzer chosen uses a solid state, dual wavelength system with a single gold-lined sample. Malfunctions of major IR com-com ponents are detected and indicated by an alarm, providing fail-safe operation. Signal detection is completely synchronous and, because of the differential technique of ratioing the zero and $CO_2$ outputs, zero drift is virtually eliminated. All critical optics are protected by sapphire windows. The reference and $CO_2$ measurements are obtained by switching discrete optical interference filters in the sample path.

The UV oxidation process and the IR analyzer were demonstrated, design goals were achieved, and sensitivities of <50 ppb were obtained for selected organic impurities. The development effort started in April 1986, and the breadboard was completed in May 1988. The breadboard system is computerized for automated operation and data logging. The development advances the state-of-the-art technology and provides the basis for future developments to support Space Station Freedom and long-term manned missions.



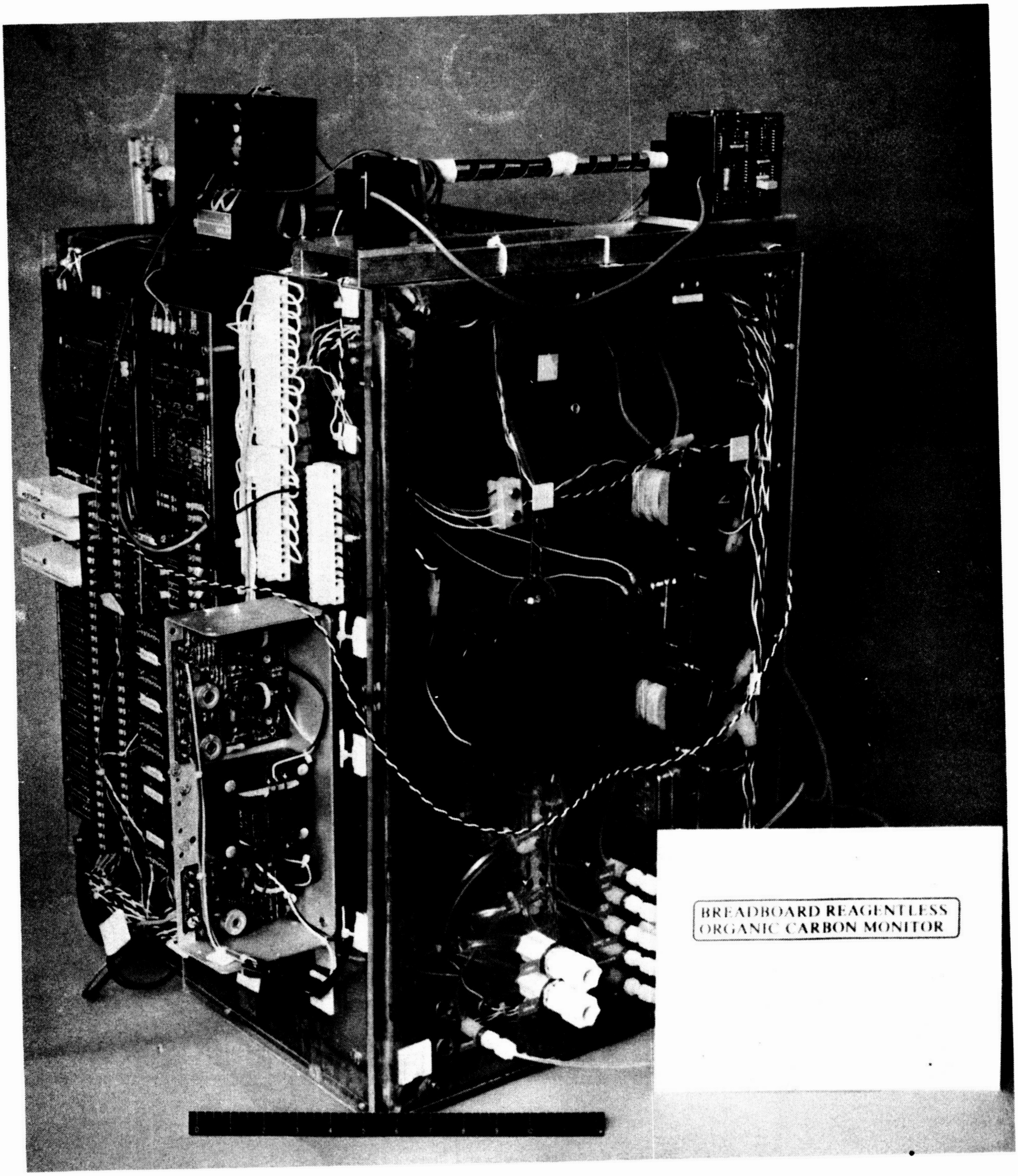
**$CO_2$ Analyzer with sample tube.**

ORIGINAL PAGE IS
OF POOR QUALITY

PRECEDING PAGE BLANK NOT FILMED



PAGE 8 INTENTIONALLY BLANK




Breadboard reagentless organic carbon monitor.

ORIGINAL PAGE IS
OF POOR QUALITY

## $O_2$ Production of $CO_2$ Electrolysis

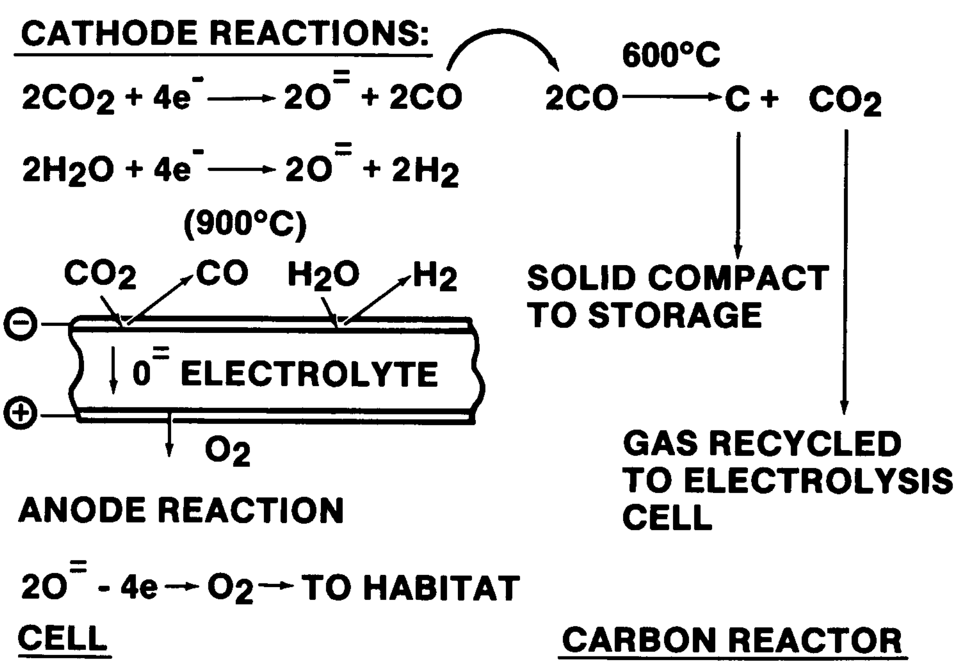
**PI: Charles E. Verostko/EC5**
**Reference SST 2**

The future of long-duration manned space missions, and Lunar and Mars habitats will depend largely on the ability to utilize regenerable life support processes. Recovery of useful products from the waste generated in closed habitats must be accomplished. The conventional method for recovering oxygen ($O_2$) from the carbon dioxide ($CO_2$) in waste breathing air has been the reduction of $CO_2$ to water, followed by the electrolysis of the water to $O_2$ and hydrogen ($H_2$). A new technology development will provide for the electrolysis of $CO_2$ at high temperature. The CO obtained can then, in turn, be thermally decomposed by a carbon formation process into solid carbon and $CO_2$. The $CO_2$ can be cycled back into the electrolyzer, which provides for full recovery of $O_2$ from the metabolic $CO_2$ produced.

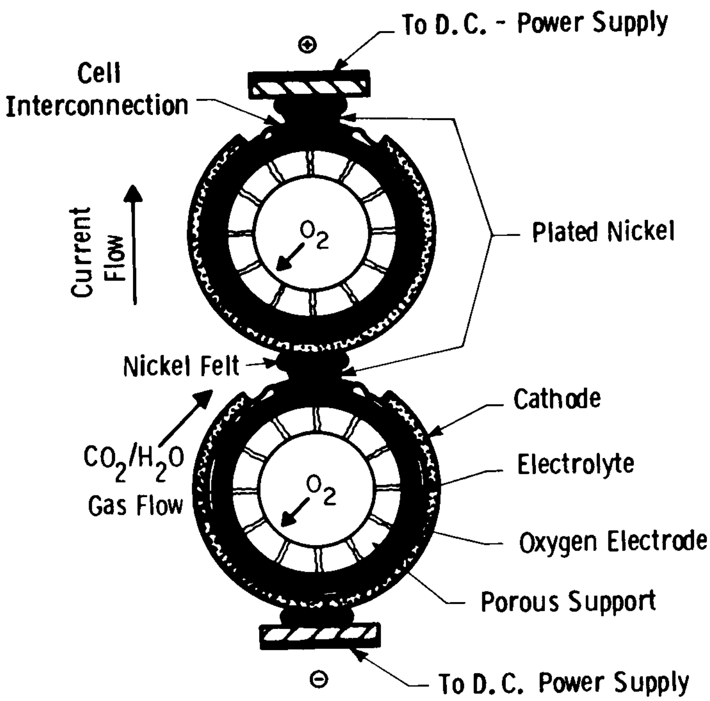
The feasibility of the $CO_2$ electrolysis concept for $O_2$ production has been demonstrated with single electrolyzer cell testing. A breadboard is currently in fabrication and consists of 16 tubular electrolyzer cells. The cells consist of thin layers of anode, electrolyte, cathode, and cell interconnection material. When DC voltage is applied across the electrolyte to the attached electrodes, $O_2$ is electrochemically pumped from one side of the electrolyte layer to the other. The electrolyte is made from yttria-stabilized zirconia, which is an oxygen ion (O) conductor at elevated temperatures. Anode and cell interconnection materials are complex oxides and electronic conductors. The cathode material is a complex metal-ceramic structure .

The principle of operation consists of reducing $CO_2$ at the cathode into $O_2$ ions. The ions are transported across the zirconia electrolyte in the lattice anionic vacancy produced by electrical charge compensation between the tetravalent zirconium cations and the trivalent yttrium cations which occupy the same crystal lattice sites. Each oxygen ion gives up two electrons at the anode, then combines with another oxygen atom to form the molecule and is released through the porous support material.

The cell development activity in 1987 produced a reliable cell which demonstrated a low operational voltage of 1.25 V. Design of a Three-Person Solid Electrolyte $CO_2$ Electrolysis Breadboard began in July 1987. The fabrication started in March 1988 and was completed in December 1988. The breadboard performance testing will be conducted in January 1989. Delivery to JSC is scheduled for February 1989. The breadboard power requirements are 400 W (AC) for the heaters and 25 A, 20 V (DC) for the electrolysis cells. The breadboard is designed to produce 6.35 lb of $O_2$ per day at the minimum cell current density of 250 mA/cm$^2$. This development provides a data base for future electrolysis systems that have application for planetary manned missions and habitats.




Operational principle of cell and associated carbon reactions.




**Arrangement of tubular electrolysis cells.**

## Computerized Man Modeling

**PI: Linda S. Orr/SP34**
**Reference SST 3**

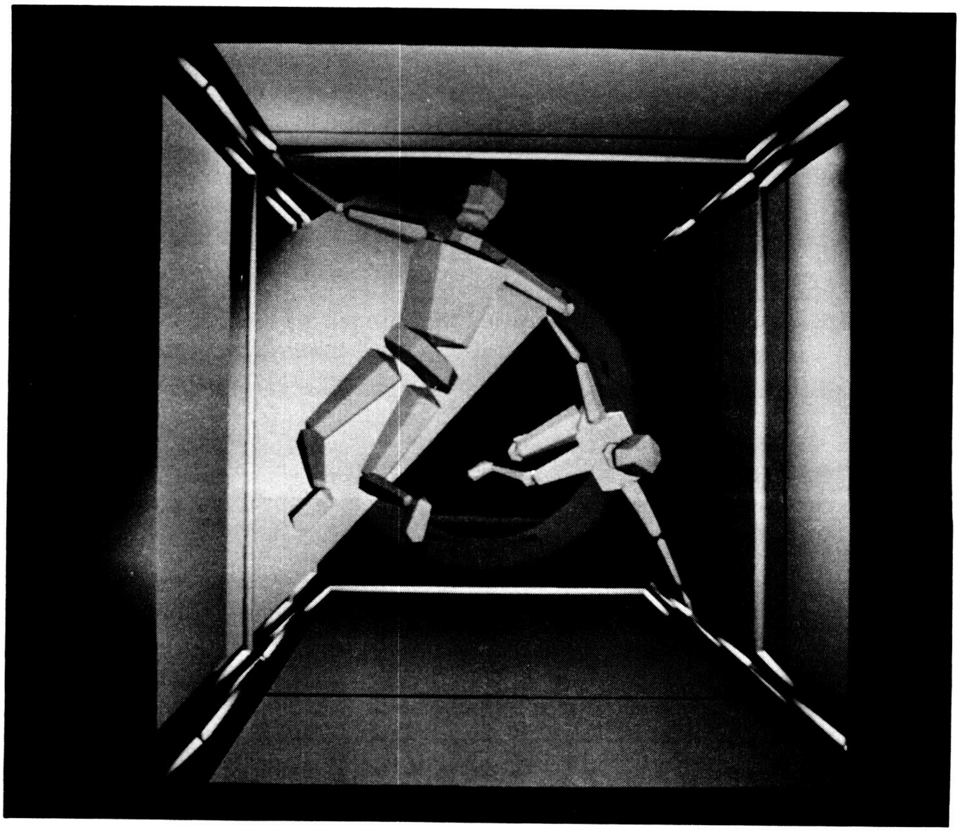
Graphics software for animation is being developed for spacecraft design analysis in the Graphics Analysis Facility (GRAF). The purpose of the system is to determine human interfaces with the spacecraft being designed, such as whether the crewmember will fit in a specified area, whether he or she can reach a designated control, and whether he or she can see, either directly or with cameras, the specified work area. To do this, computer graphics models called PLAID and JACK (not acronyms) a recurrently being used while undergoing further development to provide new features.

One key feature is the capability to develop models of any object of interest. Humans are modeled in the database in varying degrees of fidelity, from polygonal wireframes to shaded figures. These can be easily adjusted in size to represent the range of astronauts who may fly the spacecraft. Interiors and exteriors of the spacecraft are also modeled. The Orbiter and Space Station Freedom are modeled with varying degrees of complexity for various purposes. Views showing the Orbiter docked to Freedom can be easily produced, with the viewpoint being specified as some arbitrary point outside the assembly; or as seen from an Orbiter or Freedom window, or from one of their cameras. This capability, combined with animation capability, has permitted assessments of proposed scenarios for constructing Freedom. Near real-time manipulation of articulated figures has been used to generate sequences of views showing the Orbiter Remote Manipula tor System (RMS) being used to attach components of Freedom to the parts already in orbit.

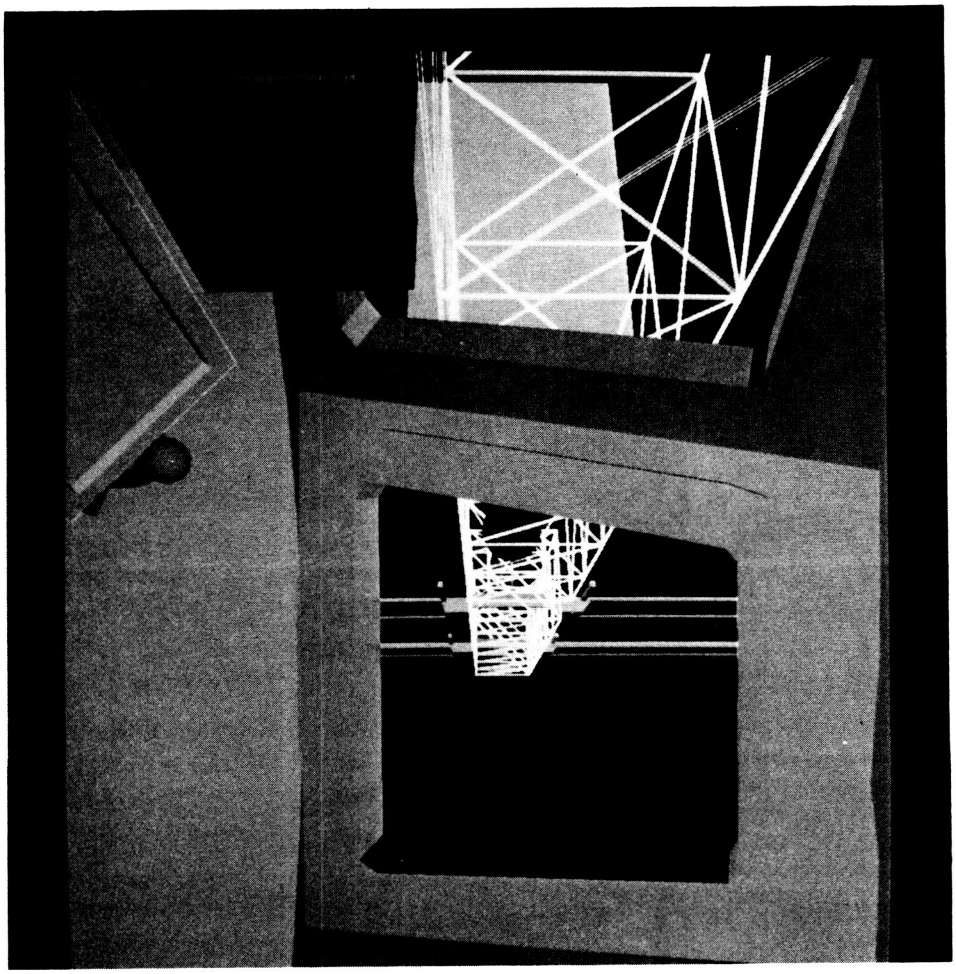
A "natural language" processor which can generate computer views using flight data files as inputs is nearly complete .An animation showing two crewmembers at the Orbiter aft crew station, simultaneously operating controls, has been generated in this manner. To achieve this, the computer had to understand sentences such as "Crewmember 1 - Switch 3 off" The software knows which object is the crewmember and which is the designated switch, and it can determine without human input what movements of which body parts are necessary to perform the specified operation. This module is in the demonstration stage at this point, but will be a powerful for tool or verifying proposed crew activities in the near future.

Viewing analyses can be generated in wireframe for highest speed, with hidden lines removedfor clear, unambiguous line drawings that reproduce easily, or as shaded, colored solid models for higher fidelity. The lighting model allows specification of multiple light sources, enabling studies of the necessity of lights in various positions.

The GRAF is filling a very real need in space flight planning by providing views of the payload bay, analyses of design concepts for Freedom, and studies of satellite servicing. It contributes directly to the Center goal of providing a safe, reliable, effective National Space Transportation System (NSTS) and to develop Space Station Freedom.



**Two crewmembers are removing a rack in the logistics module for use in the science module. This is a scene from an animation used to determine the appropriate positions for handholds and foot restraints.**



**The Space Station Freedom truss and solar arrays are shown as seen through the windows by a crewmember standing in a cupola.**

## Human Strength and Motion

**PI: Michael C. Greenisen, PH.D./SP34**
**Reference SST 4**

Knowing performance capabilities of humans in space is essential for planning efficient, successful missions. Studies of human strength and motion in zero g help provide the data needed to develop techniques for performing work in space. Also, the relative effects of proposed tools, spacesuits, and other equipment can be assessed prior to final engineering design and production. Data collection is conducted:

- under space-suited and shirt-sleeve conditions in the Anthropometrics and Biomechanics Laboratory (ABL)
- in space suits and scuba equipment, using neutral buoyancy in the Weightless Environment Training Facility
- in space suits and shirt sleeves onboard NASA's KC-135 aircraft where actual zero g is achieved by flying parabolic maneuvers.

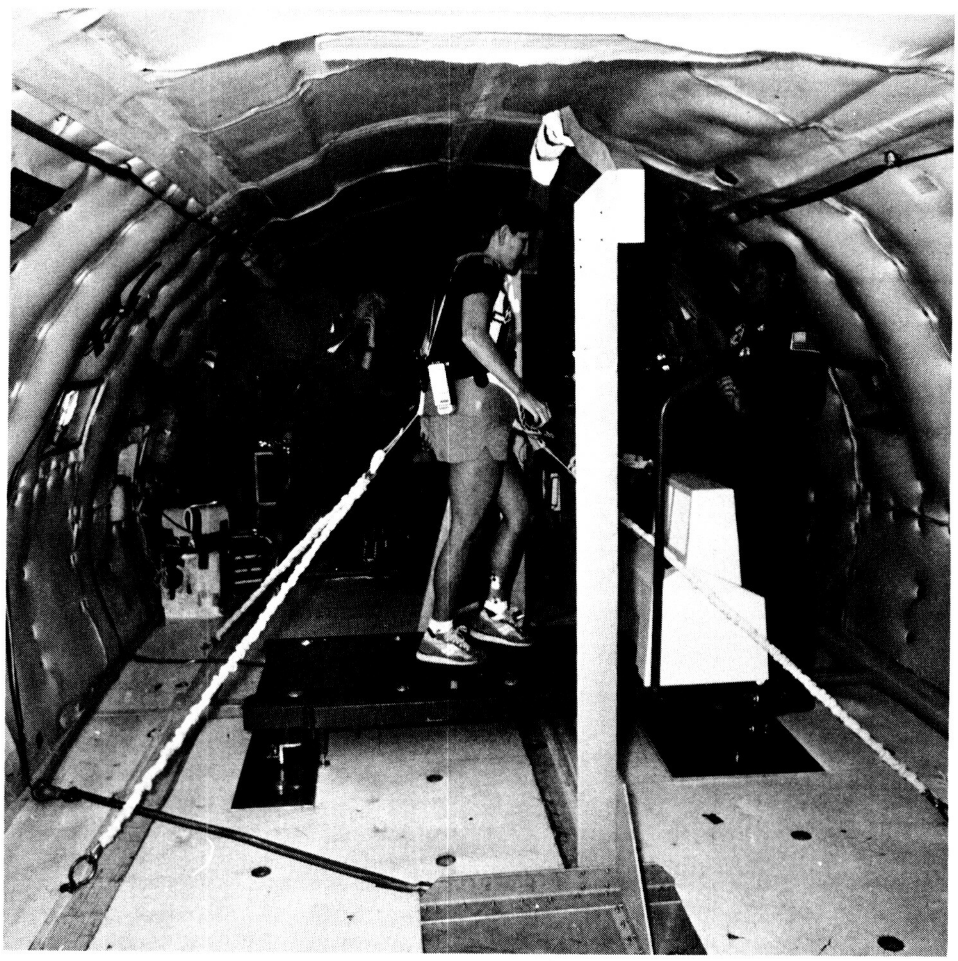
Longitudinal performance testing with a CYBEX Dynamometer, which measures the actual torque produced by the subject, is being carried out to evaluate EVA-related work capabilities and single joint articulation performance capabilities. The CYBEX has also been utilized to provide mechanical function evaluations of the AX-5 and MK III, 8.0 PSI Space Station Freedom prototype spacesuits. Recent work has expanded these evaluations to include metabolic data acquisition during the suit studies.

Separation velocity studies on the KC-135 and Precision Air Bearing Floor have investigated the separation velocities resulting during push-off by a spacesuited astronaut from a fixed object. This work estimates the acceleration and velocity which may occur from an accidental separation while performing EVA on orbit and the resulting recapture problems.

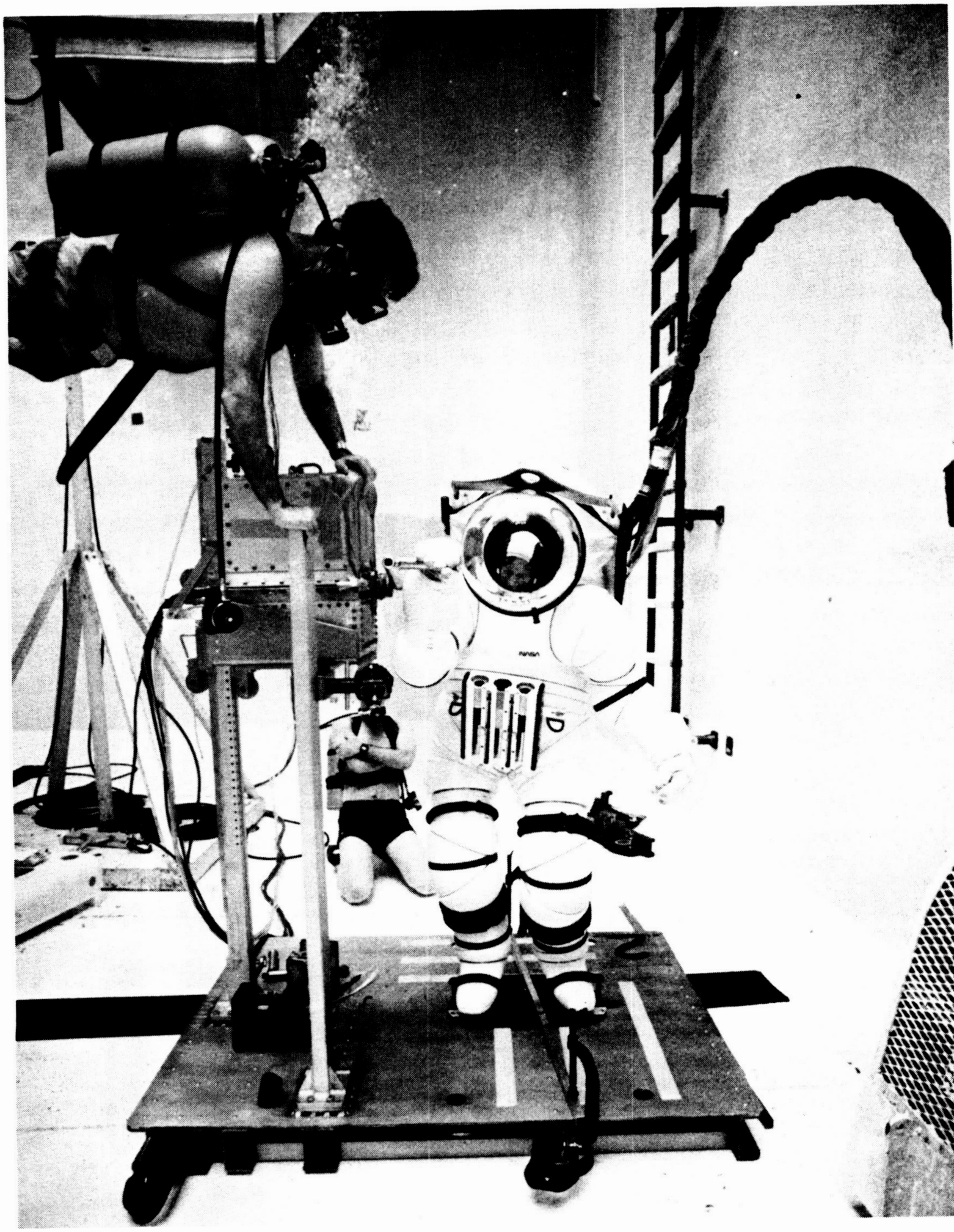
Anthropometry measures of astronaut crew seat positioning in the Orbiter established crew seat configuration for launch, ascent, and reentry. These measures provided data which accounted for the addition of the new flight pressure suit and survival gear worn during these operational conditions and were of particular importance for the flight deck performance requirements of the pilot and commander.

A load cell instrumented treadmill has permitted the analysis of walking and running z-axis impact forces during one-g and KC-135 zero-g flights. Electromyography and 3-D video motion analysis data was also collected to relate locomotion skeletal muscle contraction patterns to impact oading and stride configurations. The treadmill , EMG, and 3-D video are also in use to evaluate the locomotion patterns of the MK III space suit during simulated lunar and Mars gravity.

The laboratory is working closely with the Space Station Freedom Exercise Countermeasure Group in the design and evaluation of potential exercise equipment which will be used on S.S. Freedom. It contributes to the effective operation of the National Space Transportation System (NSTS) and is developing and evaluating technologies and capabilities for space exploration



**An instrumented treadmill is flown in simulated zero gravity in the KC-135 aircraft to measure impact forces when the subject is restrained.**



The effect of the AX-5 prototype zero-prebreathe spacesuit on human arm strength is evaluated in simulated zero gravity in the Weightless Environment Training Facility (WETF).

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

## Laser-Based Anthropometric Mapping System

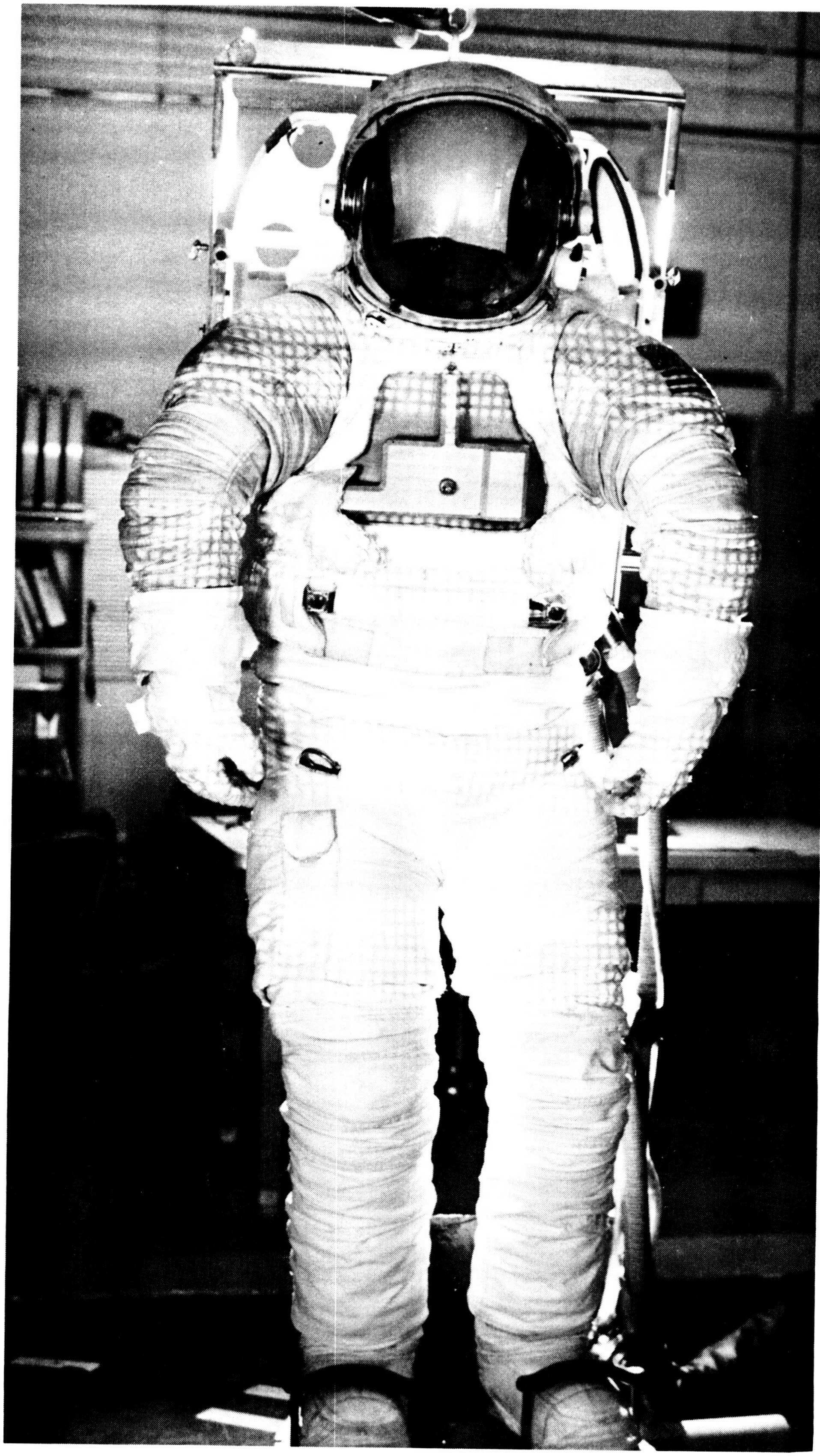
**PI: Barbara Woolford/SP34**
**Reference SST 5**

The laser-based anthropometric mapping system (LAMS) is a noncontact method for collecting three-dimensional body-size data in a computer-readable form. The LAMS, jointly developed with the United States Air Force and tested at Wright-Patterson Air Force Base, will be used to collect anthropometric data for use in spacecraft design and extravehicular mobility unit (space suit) fitting. Data from the LAMS will also be included in the man-modeling anthropometric database in support of computerized man/systems integration for manned space flight.

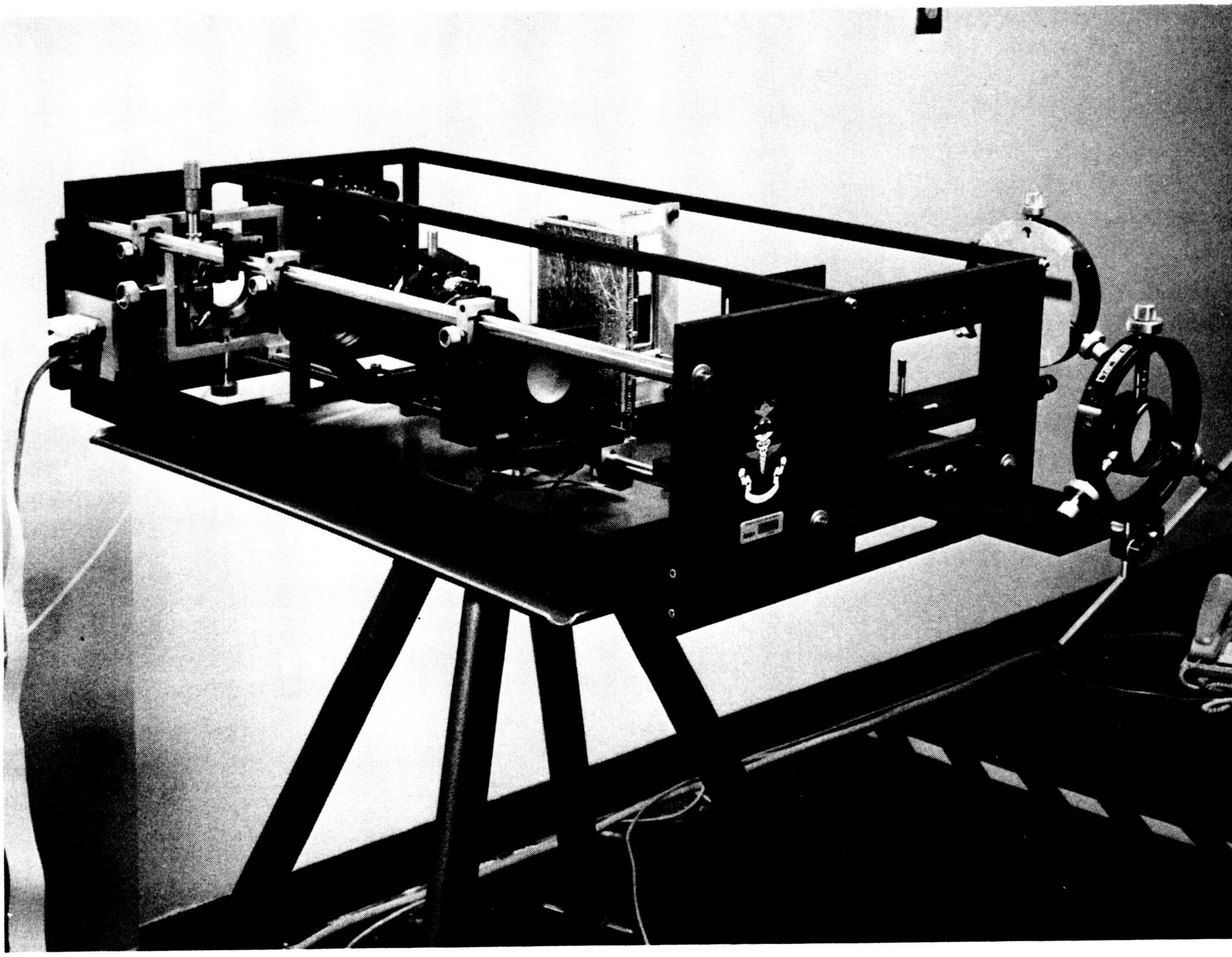
The LAMS was installed at Johnson Space Center (JSC) this year. Upgrades to the computer controls were made to enable more nearly autonomous operation and to take advantage of advances in computer technology over the past few years. A much smaller computer is now used to control the laser, optics, cameras, and video analyzers. The software to accept camera views taken from separate cameras and from different points of view of the subject was developed at the University of Pennsylvania and will be installed at JSC for LAMS use in the JSC Anthropometrics and Biomechanics Laboratory.

Data provided by the LAMS will help in designing spacecraft, crew systems, and habitats, in providing a safe and effective National Space Transportation System (NSTS), and in building Space Station Freedom. This is a new technology with many benefits in the design of systems for space transportation and exploration.

In the future, the system capabilities will be enhanced with software for automatic data extraction. A flight system is envisioned to collect measurements to assist in quantifying effects of space flight on humans.



**A coded array of beamlets is projected on a space suit to measure its surface location.**



The equipment for generating beamlets includes a laser, a beam splitter, and an electro-optic shutter.

## Human-Computer Interaction

**PI: Dr. Marianne Rudisill/SP34**
**Reference SST 6**

Research in the Human-Computer Interaction Laboratory focuses on analyzing interactions with computers and on the effectiveness of advanced display and control technologies. The research centers around three major topics:

- System design
- Performance modeling
- Operator (user) modeling

In the research related to system design, a series of experiments have examined a computer-based system for displaying procedural information. For these experiments, computer-based methods for displaying procedural information were modeled on current Space Shuttle malfunctions procedures. The experiments compared text and flowchart display modes and evaluated the effects of the amount of information available to the user. Significant advantages in response time and accuracy generally were observed with the graphically-oriented flowchart format. However, the advantage of the flowchart over text depended on amount of information displayed.

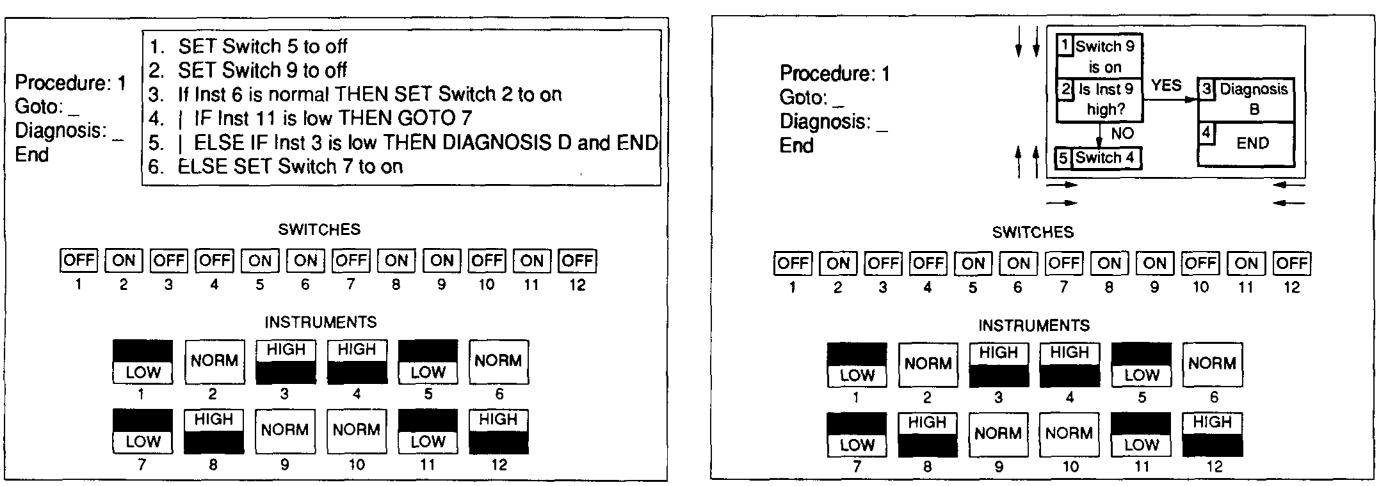
In the research on performance modeling, one key project has focused on the mechanisms underlying interactions with graphical displays, which will be used heavily in Space Station Freedom to communicate system status to the crew. The basic features of graphs were found to include:

- Physical features (e.g. points, lines, planes, and angles)
- Perceptual features and complexity
- Informational features such as the number of dimensions in the data

Response time increased by as much as 50 percent across the range of values in the three features. In addition, the impact on performance of varying the features depended on the task that the user performed. Research was also conducted to develop a preliminary performance model of human interactionwith direct manipulation controls, such as mice or joysticks. These devices may be used in human-computer interactions in Space Station Freedom.

Work in operator modeling has centered around research on the rules by which an operator's knowledge of physics is applied to problem-solving and decision making, especially in space-based physical systems. Other research currently underway is designed to examine the models that various types of experts have about interactions between humans and computers. The application of operator modeling techniques to knowledge acquisition has been a principal focus of the development of the Knowledge Acquisition and Representation Toolkit. Operator models will enable design of effective human-computer interfaces for Space Station Freedom.

This lab has provided guidelines, requirements, and standards used in the NASA Man-System Integration Standards, the Space Station Freedom Program Human-Computer Interface Guide, and the Space Station Workstation Requirements and Definition.




**Diagnosing a fault using a computer-based display of procedures was more accurate and faster with a graphical, flowchart format (right display) than with a text format (left display).**

## Human-Telerobotic Interactions

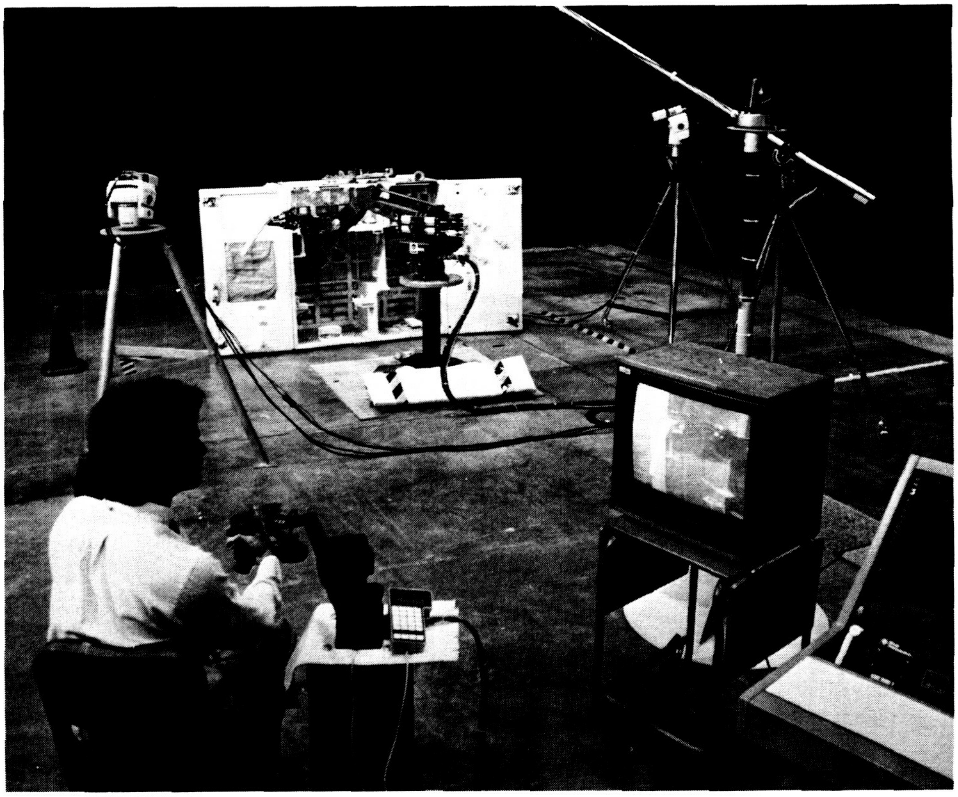
**PI: Jay Legendre/SP34**
**Reference SST 7**

A telerobot is a mechanical manipulator device that at times can be under direct real-time control by a human, and at other times can perform some tasks autonomously under computer control with a human acting as supervisor. On Space Station Freedom, over half a dozen manipulator arms are being planned to assist with its assembly, maintenance, and inspection as well as with satellite servicing. When humans are in the control loop, they are the most crucial and variable element in the system, the focus for the feedback of information about the telerobot's activity and the origination point of control inputs to the telerobot. Work in the Man-Systems Telerobotics Laboratory (MSTL) analyzes human factors of the interface between an operator and a telerobot to optimize the performance of the telerobot system, and to ensure that safety and user preference considerations are taken into account. Three major areas of this user interface are information feedback, control inputs, and workstation design.

Information about the telerobot's position, orientation, state, etc., is fed back to the operator via television displays, computer displays, and so on. Too much information fed back to the human operator can have serious adverse effects on system performance. Therefore , attention is given to camera positions and numbers, monitor types and numbers, force feedback displays, and displays of other systems information. These factors are studied to help design user interfaces in which the operator's mental and physical workload is minimized, while at the same time ensuring that the telerobot system is performing its tasks quickly and accurately, and in a safe manner.

Inputs are made by the human to control telerobot manipulator arm location and velocity, camera orientation, telerobot grapple arms and torso positions, lights, and other sensors. The ability of the human to quickly and accurately reposition the telerobot in a natural manner is largely dependent on the selection and design of appropriate control devices. Studies have focused on hand controllers and camera control devices.

Once telerobot displays and controls have been selected based on task demands, the items must be laid out into an integrated workstation. Operator reach limits, forces and torques, viewing angles, and restraint systems are evaluated and incorporated in panel layouts for the Space Station and the Orbiter. Since the Orbiter, and all future manned spacecraft will use telerobots frequently, MSTL work is in direct support of the goals to promote safe operation of the National Space Transportation System and Space Station Freedom, and to promote further exploration of the solar system.



**Evaluation of operator using direct and displaced camera views to perform a remote manipulation task.**

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH


Example of control devices being evaluated for telerobot manipulator arm control: 6 degree-of-freedom hand controller, 3 degree-of-freedom rotational and translational hand controllers, full-size master controller, miniature master controller.

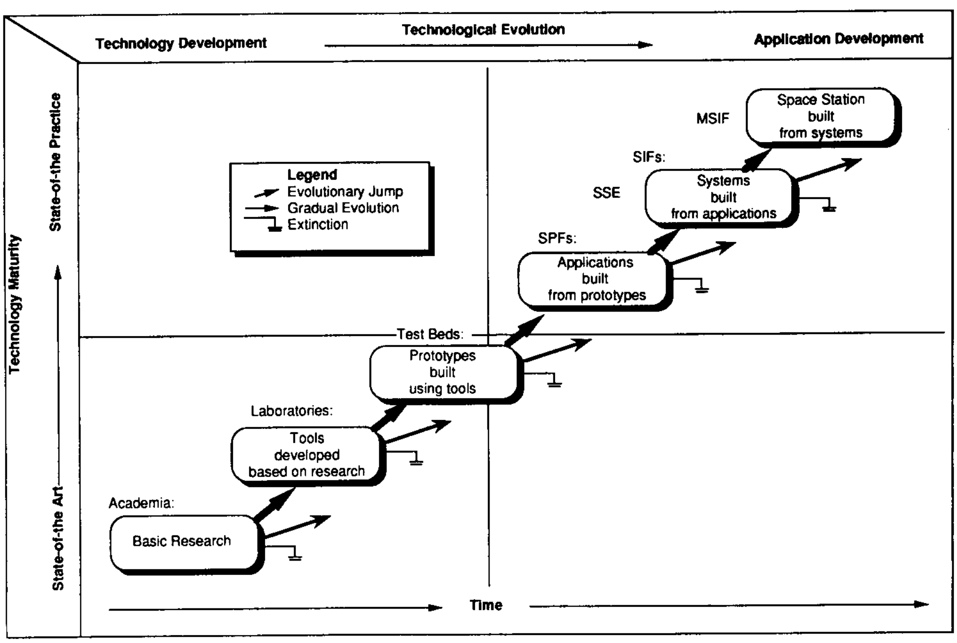
## Advanced Automation Test Beds

**PI: Kenneth Crouse/EF5**
**Reference SST 8**

Advanced automation will play a key role in bringing Space Station Freedom to the level of autonomy needed for safe, efficient operations over its 20- to 30-year lifetime. In order to be able to deploy advanced automation on Space Station Freedom, the technology must be developed and tested on the ground, integrated with all the systems with which it will interact, and tested in space in the operational environment. This project focuses on defining the requirements for ground-based facilities to be used to develop and test advanced automation to make it ready for in-space testing.

During FY88 a comprehensive literature review was conducted to determine the nature of ongoing and planned uses of advanced automation in the Space Station Freedom Program (SSFP). An extensive tour of laboratories and test beds at various NASA centers and outside of NASA was conducted to establish a benchmark with regard to the capabilities of existing facilities. Numerous interviews were conducted with persons involved in software development, systems testing, and integration, including personnel responsible for the Software Support Environment (SSE) and the Multi-System Integration Facility (MSIF). The SSE supplies tools and rules to support software development at Software Production Facilities (SPF's) and software integration at System Integration Facilities (SIF's). The MSIF is the place where different systems are integrated and tested as the final step before going into space. Some initial approaches relating to the evolution of SSFP facilities were identified in which environments for technology development in laboratories and test beds and in which environments for application development in the SSE would evolve in parallel with Space Station Freedom. The report, "A Review of Space Station Freedom Program Capabilities for the Development and Application of Advanced Automation," presents the FY88 results.

In FY89 the project will identify the goals for the evolution of SSFP facilities and capabilities, formulate concepts and strategies for reaching those goals, and develop test bed-specific plans for evolution. Additional plans will be developed for the SE and the MSIF.




Advanced automation technology evolution.

## Expert System for Crew Procedures Execution

**PI: H. K. Hiers/EF5**
**Reference SST 9**

Due in part to the technological challenges of the Space Station Freedom program, much attention is being focused on expert systems that operate in a real-time environment and that interface with flight crews and/or flight subsystems. The Rendezvous Expert System (REX) is a product which addresses this general interest in expert systems.

The rendezvous application was made especially attractive by the availability of the Systems Engineering Simulator (SES) Laboratory, a major real-time engineering simulation facility at Johnson Space Center (JSC). The SES is used extensively for real-time engineering evaluation of advanced concepts and for on-orbit procedures development and flight crew familiarization. It provides an excellent environment for engineering evaluations, procedures development, and crew familiarization with a real-time expert system integrated in an appropriate and realistic environment. Interfaced with the SES on-orbit simulation, the REX would encounter and would be required to deal with many of the technical and procedural problems presented by an Orbiter in flight.

The REX, conceived as a crew "assistant" in performing an Orbiter rendezvous with a target in space, was initiated in FY87. A summary of the accomplishments of that year's work includes formal REX requirements definition; design and implementation of hardware and software interfaces; implementation of the expert system rules for monitoring guidance, navigation and control (GN&C) sensors; and minor modification of SES math models.

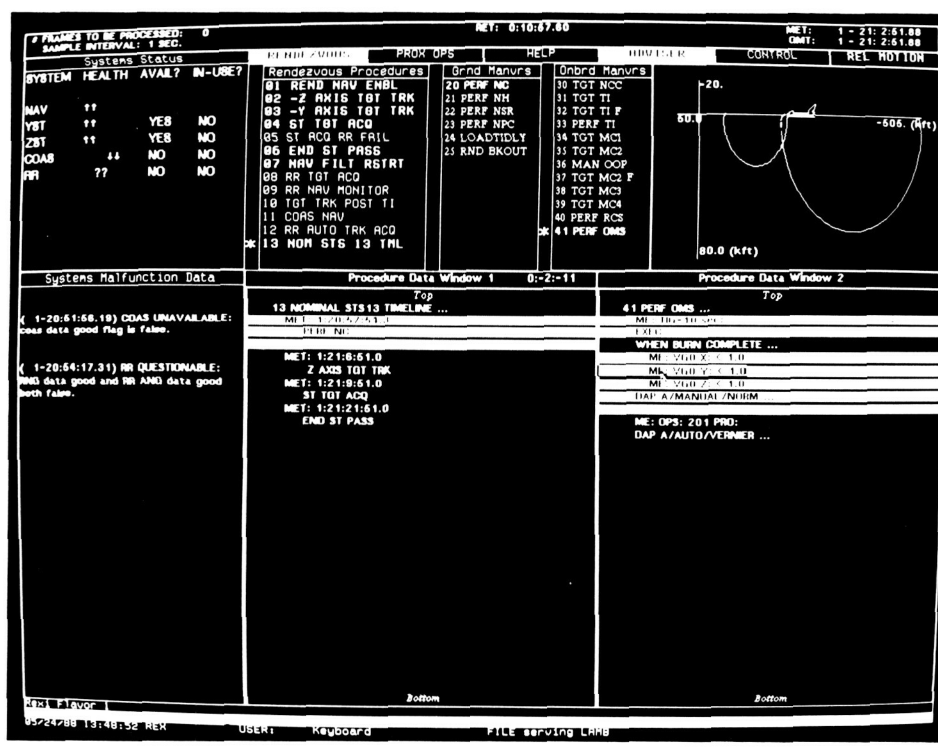
Continuing the REX development in FY88, the primary results were:

- The implementation of representative rendezvous procedures
- Implementation of the REX crew interface software
- Integration of the REX hardware and software with the SES.

In April 1988 the prototype REX, interacting with crew and SES in a typical rendezvous scenario, was demonstrated.

For the remainder of the fiscal year, feedback on the REX was solicited in demonstrations to astronauts and other interested members of the technical community. To the extent possible, suggested improvements to REX were incorporated. At the close of the fiscal year, the final REX design and lessons learned were being documented. A proposed follow-on task, building on the existing REX, has been funded for FY89.

The REX has four primary functions. First, it performs the overall procedure management, that is, recommending the execution of the appropriate rendezvous procedure in a nominal rendezvous timeline, and, to a limited extent, recommending the appropriate contingency action in the event of sensor failure. Second, the REX monitors each step of the procedure performed by the crew, seeking confirmation of the action by examining the simulated telemetry data from the SES. Third, the REX continuously monitors the telemetry for indications of rendezvous sensor failures, reporting the results of its tests to the procedure management function. Finally, the REX provides a dynamic CRT plot of the Orbiter/target relative motion and, subsequent to Orbital Manuevering System (OMS) or reaction Control System burns, a plot of the predicted new path of the Orbiter.




REX display.

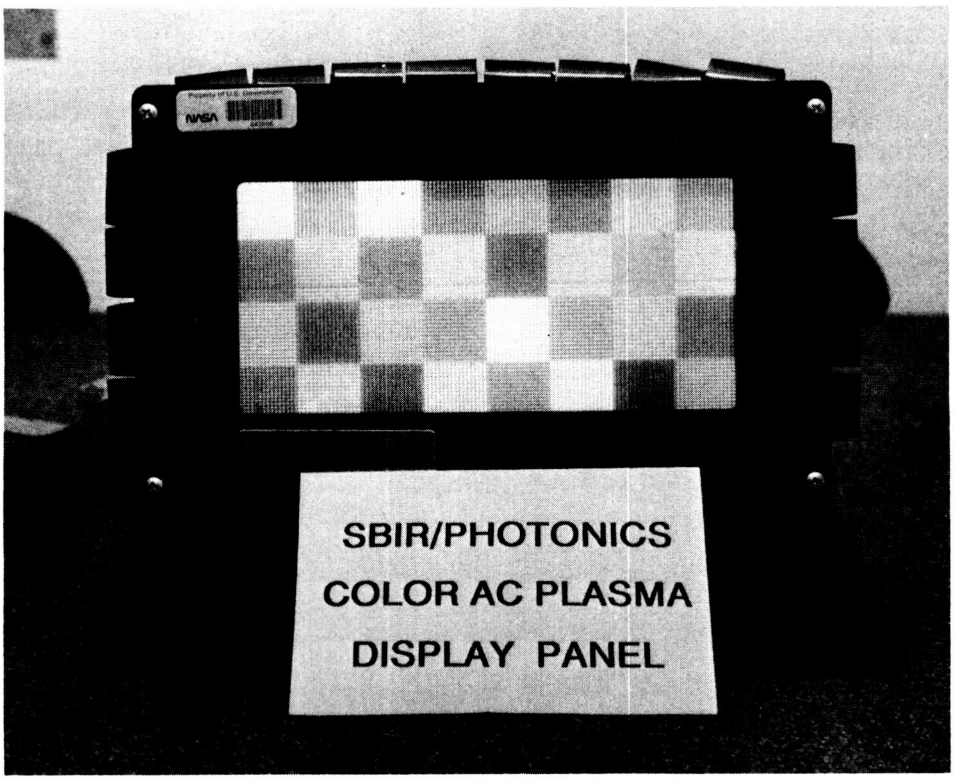
## Full-Color AC Plasma Flat Panel Display

**PI: A. J. Farkas/EF**
**Reference SST 10**

Full-color, large-area, dot-matrix flat panel displays are not currently available. Plasma displays represent one of the leading large-area flat panel color technologies. In a Phase I Small Business Innovation Research program with Photonics Technology, Inc., both the operating window voltage and panel brightness were improved by 600 percent, resulting in the world's brightest dot-matrix flat panel color emissive display. This display, which has a diagonal of 8.5 inches, an area luminance of 64 fL, and a contrast ratio of over 145:1, was delivered to NASA with drive electronics and demonstration software. The Phase I program involved the fabrication of 23 experimental color panels with four sets of specially designed color drive electronics. Phase I experiments on these panels suggest that almost a two-order of magnitude improvement in panel brightness is feasible. Photonics proposes in Phase II to deliver a 14-inch, sunlight-readable, high-resolution, full-color display, having 16 levels of gray scale, a full-video interface, and demonstration software. This panel will be a prototype for Space Station Freedom applications. In order to achieve optimum performance, a minimum of 84 full-color panels and 8 sets of drive electronics will be constructed with the major panel design and fabrication parameters systematically varied. This display will have broad commercial, industrial, scientific, and military applications

.A full-color flat panel display has numerous applications besides that for the Space Station. Other applications include:

- Space Shuttle Orbiter" Glass Cockpit"
- High-resolution color graphic smart terminals
- Avionics
- Medical imaging
- Engineering workstations
- CAD/CAM
- Scientific instruments
- Military command and control
- Navigation and communication systems
- Portable computers
- Operating room displays
- Air traffic control
- Radar and sonar systems
- Video displays
- Personnel training and simulators
- Interactive educational systems
- Sensor monitors




Full-color AC plasma flat display panel.

ORIGINAL PAGE IS
OF POOR QUALITY

## Helmet- Mounted Display Human Factors

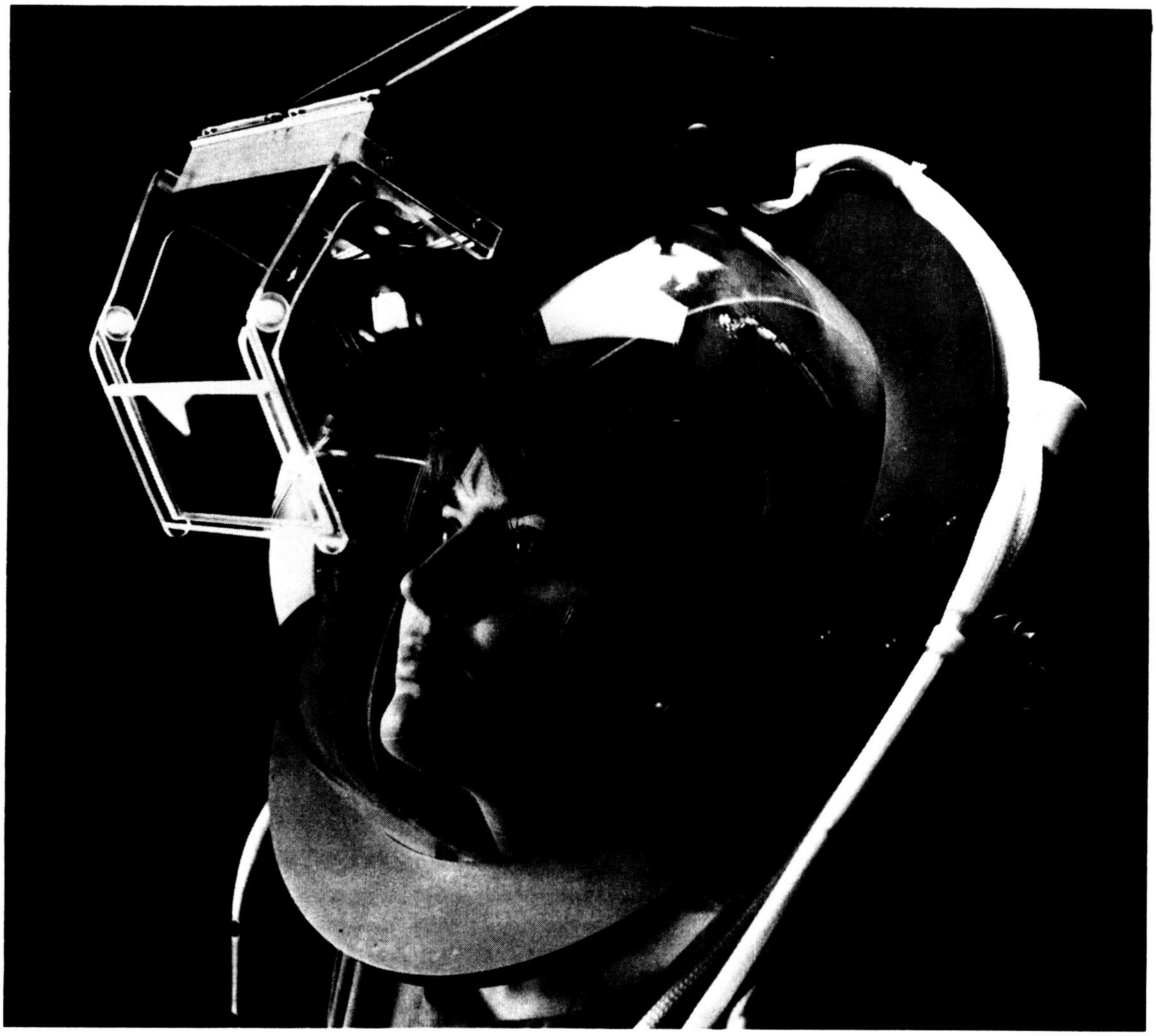
**PI: Barbara Woolford/SP34**
**Reference SST 11**

A helmet-mounted display (HMD) is being developed to increase crew productivity and safety in extravehicular activity (EVA). An HMD would replace the cardboard cuff checklists and the displays and controls module (DCM) currently used. However, it will only be useful if it can be used quickly, easily, and effectively without interfering with the task at hand.

The HMD displays and controls must be readily accessible to the user while he or she is working. Therefore, a combination of voice commands and flexible displays is being studied. The displays must be capable of showing everything from numerical values of suit parameters to detailed photographs and schematics of the object being serviced. Candidate formats for the displays have been designed and evaluated by crew trainers, crewmembers, and EVA engineers. Similarly, the use of a voice command system will leave the astronaut's hands free while the displays are being selected. The emphasis this year has been on developing a vocabulary that is concise, complete, and natural. Tests have been conducted on words to determine separability by commercial voice analyzers. Also, techniques for updating voice templates during the performance of EVA have been studied and evaluated.

Technology development this year has centered on interfacing the prototype HMD's to computers for generating the displays and on developing tools for easy design and presentation of displays. During the coming year, displays will be evaluated experimentally for clarity and ease of use. The vocabulary will be refined, and the operating system for the HMD display logic will be further developed.

The advantages of a well human-factored helmet- mounted display for Space Station Freedom will be seen in increased safety and productivity. This is a necessary system for further space exploration.



**The prototype helmet-mounted display presents LCD images on a partially reflective plate mounted above the subject's direct line of sight.**

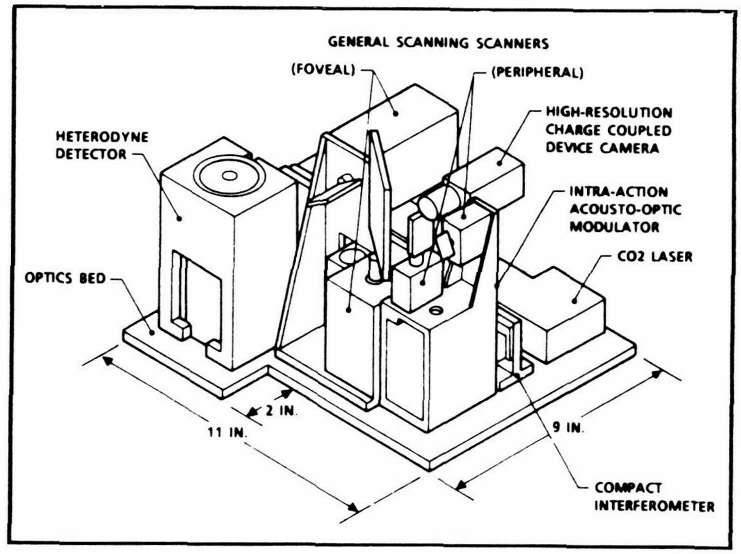
# Hierarchical Three-Dimensional and Doppler Imaging Lidar

**PI: K. F. Dekome/EE6**
**Reference SST 12**

This is a Small Business Innovation Research (SBIR) project to develop an improved three-dimensional imaging lidar. The lidar will be applied to robotic vision and spaceborne target tracking for rendezvous and docking, remote manipulator and autonomous robot operations, satellite servicing, and proximity operations.

This three-dimensional mapper provides Doppler as well as range and intensity images and programmable/adaptable scans, consisting of a fine resolution fovea and lower resolution peripheral vision (patterned after the human eye). The high resolution can be placed anywhere within the sensor's field of view according to the region of most interest, while the lower resolution peripheral vision provides for simultaneous monitoring of other objects or target features and obstacle avoidance. The Doppler imagery provides an additional discriminator for object recognition and could be useful in identifying the rotation axis of a spinning satellite to aid in approach and grappling.

Phase I produced a working laboratory model (not deliverable) which was successfully demonstrated in 1988. A deliverable prototype, which could be integrated with the Extravehicular Retriever or other robotic ground demonstration devices is planned for Phase II.




Imaging lidar assembly design.

Imaging lidar breadboard.

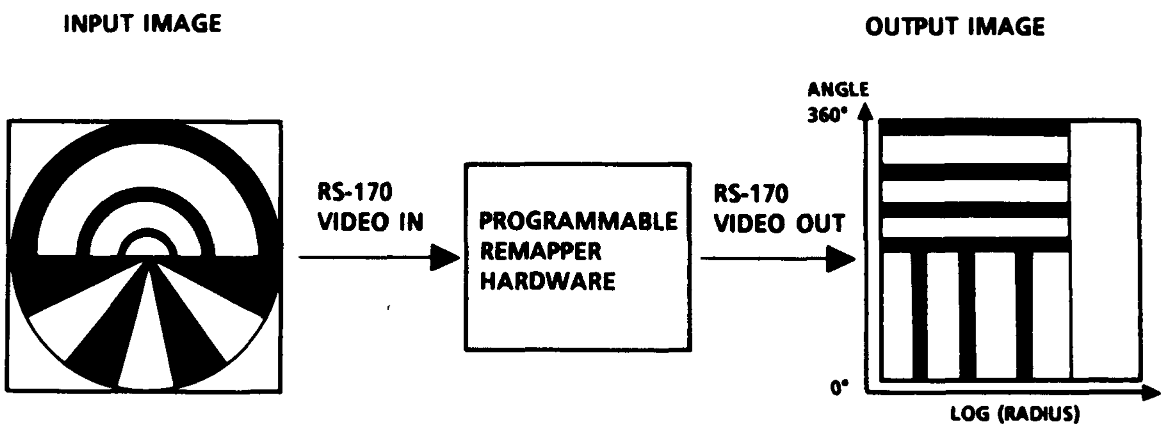
ORIGINAL PAGE IS
OF POOR QUALITY

## Programmable Remapper

**PI: T. E. Fisher/EE6**
**Reference SST 13**

The Programmable Remapper is a novel image processing tool developed at NASA and constructed by Texas Instruments for performing virtually unlimited geometric coordinate transformations on video rate imagery. This type of machine is required for real-time pattern recognition algorithms in projects such as JSC's Optical Correlator project for rotation and magnification insensitivity. NASA applications include robotic vision for the Extravehicular Activity Retriever (EVAR), satellite servicing vehicles, and remote manipulator operations. The Programmable Remapper is also being used by a Small Business Innovation Research (SBIR) Phase II contractor working on the log-polar transformation for real-time space tracking applications. Future uses for the Programmable Remapper include preprocessing video imagery in a Mars lander scenario. This tool also has many applications in the private sector, including a Technology Utilization Office effort to provide improved vision for human patients with visual field defects such as Retinitis Pigmentosa (tunnel vision) and Age Related Maculopathy (central blind spots). These uses and others make the Programmable Remapper a valuable tool for NASA, the Department of Defense, and industry. It is currently the subject of a patent application, which names two JSC inventors.

During 1988, the Programmable Remapper program has completed several milestones including delivery of the actual hardware from Texas Instruments in May. The Programmable Remapper has since drawn increasing interest from industry, Government, and academia, and is accumulating nationwide recognition as a result of technical presentations and onsite Programmable Remapper visits.




Log polar transformation.

## Optical Processing

**PI: R. D. Juday/EE6**
**Reference SST 14**

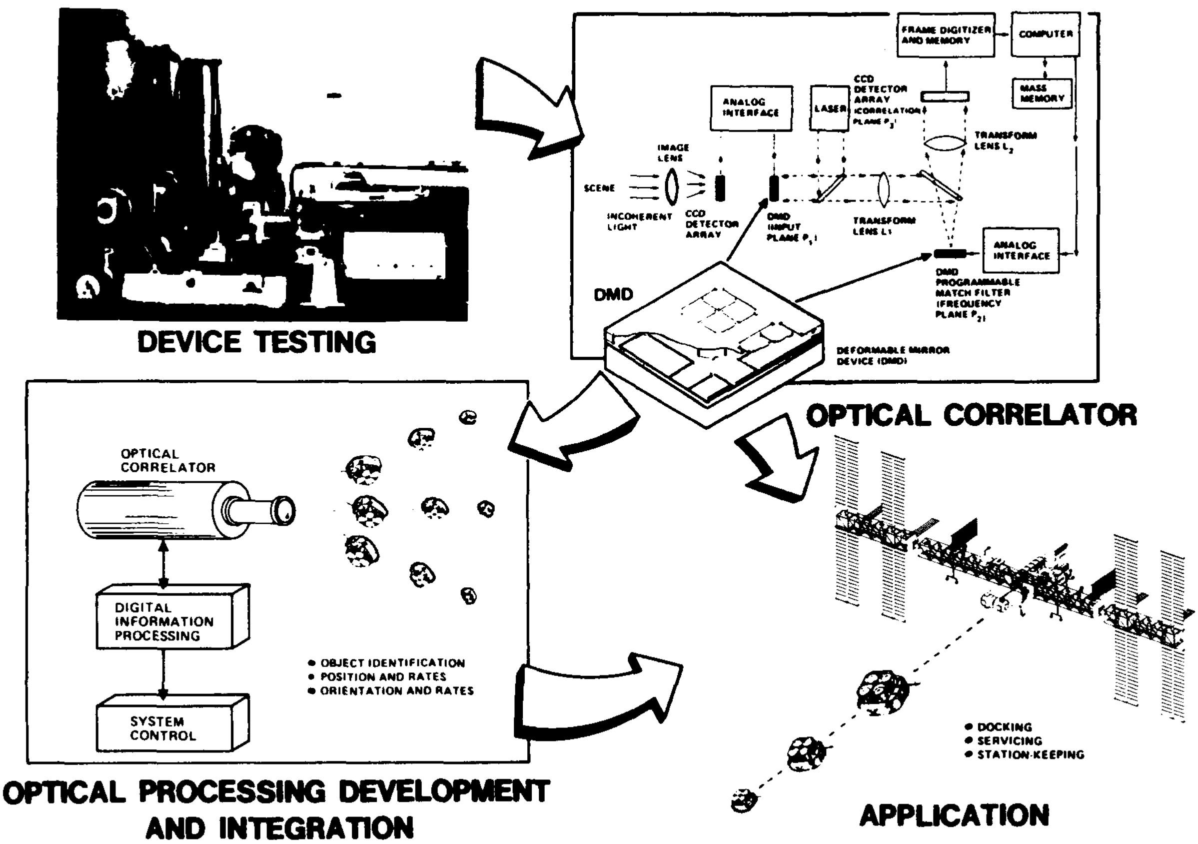
Optical processing offers the possibility of faster, lighter weight, simpler vision systems for some applications that do not require the great power and generality of vision by digital image processing. The in-house investigation is advancing on several fronts - the development of advanced spatial light modulators; the development of special filtering algorithms for use in phase-only optical correlators, including impulse deconvolution and correlation pattern shaping; and geometric image remapping.

The Tracking and Communications Division is cooperating in or directing work for each of these activities performed by several organizations including the National Bureau of Standards, various imilitary organizations (Army Missile Command, Naval Research Labs, and Rome Air Development Center), a large number of universities (Texas A&M University; two University of Houston campuses, University Park and downtown; Carnegie-Mellon University; Cooper Union University; the University of Washington at Seattle; the University of New Hampshire; and the University of Missouri at Kansas City), and other NASA centers (Ames and the Jet Propulsion Laboratory).

The optical processing of video data using spatial light modulators (SLM's) in a real-time optical correlator is being developed for use in robotic vision and proximity operations, such as docking and stationkeeping. The system should be capable of identifying a specific object (or feature) and then determining the azimuth, elevation, range, roll, pitch, and yaw of the object. The hybrid system will make use of the high speed of optical correlation by transferring optical filters to the SLM at a rate of 50 filters per second from a digital computer, which will evaluate the correlator output from the charge coupled device (CCD) imager and choose the next filter.

In order to realize the benefits of such a system, sets of filters and logical procedures for accomplishng specific tasks are being developed. Current work includes hardware evaluation of these filters and procedures in the newly established Robotic Vision Laboratory.

Technical spin-off's of this program include possible aid for persons suffering from impaired vision, in addition to the more obvious applications in industrial robotics.




Programmable mask technology.

## Development of a Hygiene Waste Water Filter

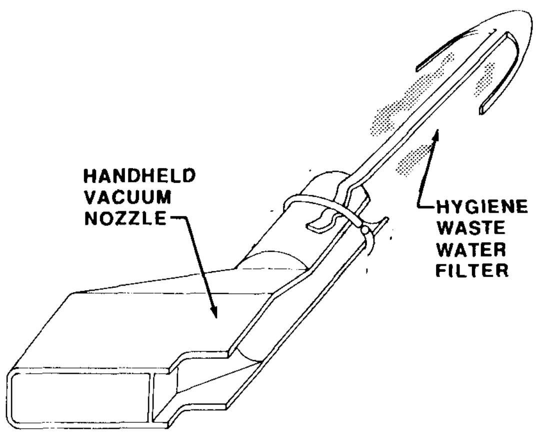
**PI: Rafael Garcia/SP44**
**Reference SST 15**

The design of NASA's personal hygiene and housekeeping facilities to support future space programs includes a shower, laundry, dishwasher, and hand washing facilities. The water from these facilities will be recycled by the water reclamation subsystem of the environmental control and life support system. To reduce the cleaning and preventive maintenance of the personal hygiene and housekeeping subsystems and the expendables for the water reclamation subsystem, a development program for a hygiene waste water filter was initiated. The filtering system is designed to remove particles comprised of hair, lint, and other debris from the hygiene waste water prior to delivery to the water reclamation subsystem.

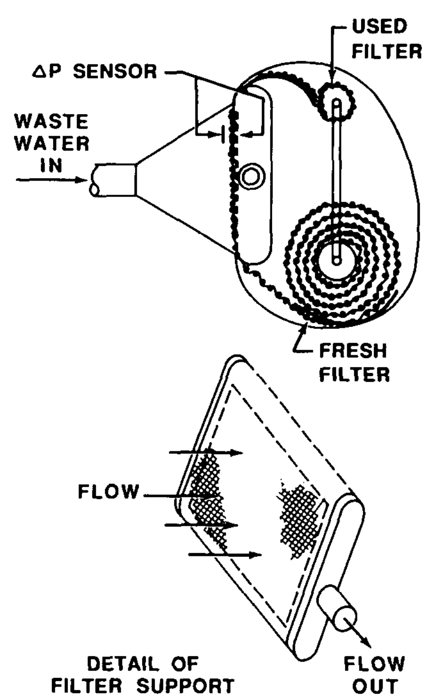
In FY88, during phase one of the program, a filter for use only in a whole body shower was prototyped and tested. The filter is packaged into the hand-held vacuum nozzle and discarded after one use to reduce the possibility of cross-contamination between crewmembers. The second phase of the program was directed towards design of a continuous waste water filter. The concept and materials were the same as the shower filter but packaged differently. This filtering system used a cartridge of filter material (100 mesh polyester) required for up to 35 days operation. The continuous waste water filter is positioned close to the waste water collection point to reduce debris passing through the plumbing. Waste water is forced through the filter, which traps debris, lint and hair. When differential pressure across the filter exceeds predefined specifications, a motor drives the filter material until specifications are met. Crewmembers are signaled automatically to replace the filter cartridge when the supply of material is almost depleted.

These activities were directed towards definition of design configurations for both filtering systems. For the shower filter, tests and evaluations were conducted to select the most efficient filter configuration. A laboratory test evaluated different foam-suppressant products (defoamers) that might be dispensed by the filter. Seven products were initially tested, with the two best performers evaluated further in a microgravity environment. For the waste water filter development, tests were performed to define requirements for a laundry detergent. A prototype of the filter unit was built to define design parameters, such as size, shape, and pressure drop for the filtering system.

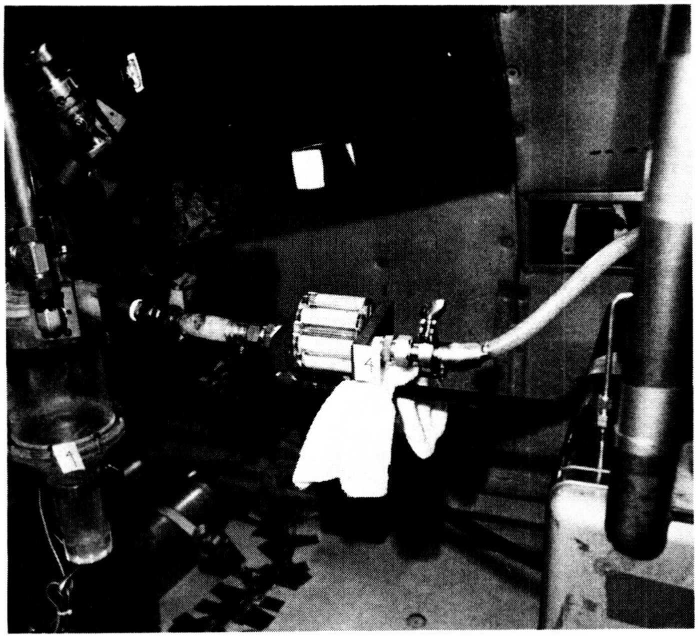
Research activities demonstrated feasibility of these filtering systems and identified areas for additional study. Technology and hardware developed during this activity will potentially solve the technical problems of filtration and phase separation of the hygiene waste water. In addition to the technical benefits, considerable savings in weight and crew maintenance time can be realized.



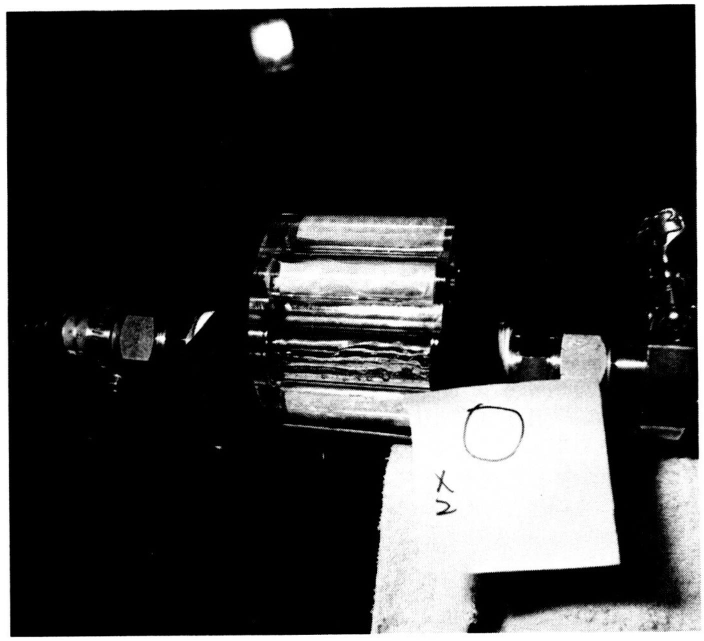

**Proposed configuration for the hand-held vacuum nozzle with disposable filter.**



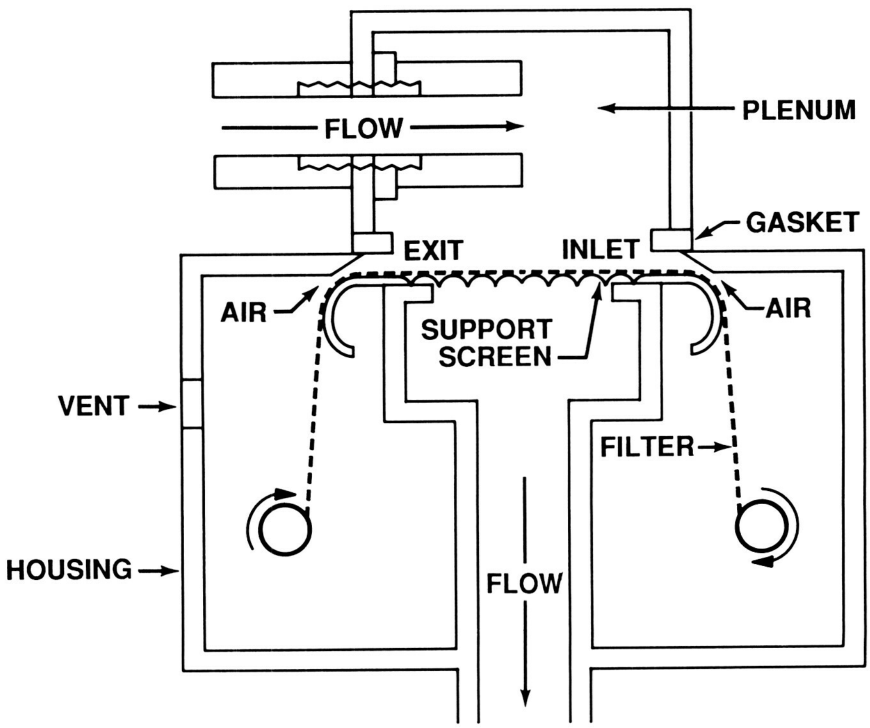

**Proposed configuration for the hygiene waste water filter.**



Test set up aboard the KC-135 aircraft. Hygiene waste water was forced through the hand-held filter prototype during the period of microgravity.



A multi-filter cartridge was designed to facilitate the microgravity evaluation of the vacuum nozzle filters.




Test configuration of the hygiene waste water filter.

## Development of an Air/Liquid Separator for the Microgravity Hair Cleansing System

**PI: Rafael Garcia/SP44**
**Reference SST 16**

With NASA's commitment for longer duration flights, the need for personal hygiene facilities and equipment to assist the crew-members in performing regular and customary personal hygiene tasks becomes a high priority.

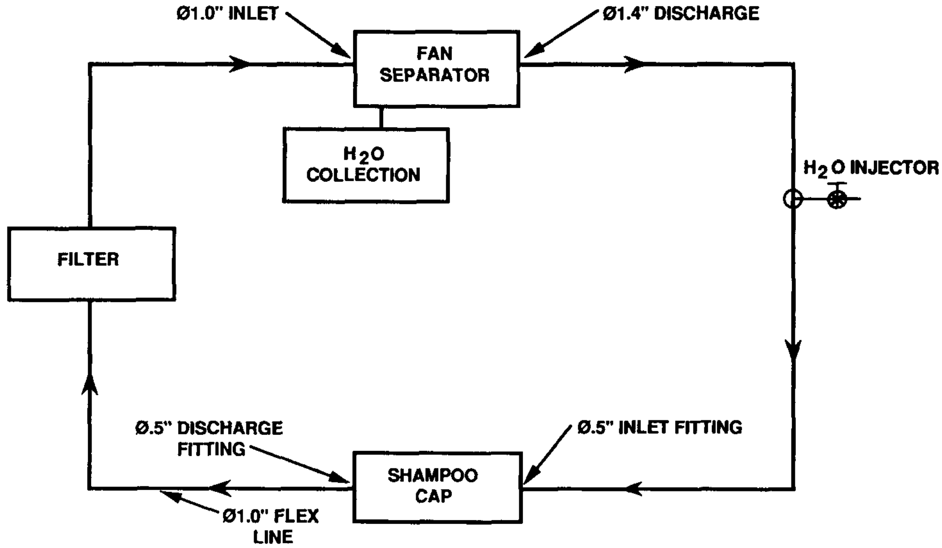
One of these facilities/ equipment is a microgravity hair cleansing system. This system is designed to provide the crew-member with a water source to clean his/her hair and with a vacuum source to collect the waste water to be processed or disposed. The air and waste water collected during the operation of the hair cleansing system needs to be separated prior to its delivery to the processing system. The separation of the air and liquid in a microgravity environment has become one of the major problems in the design of the water systems. For this reason, a development effort was initiated to better understand the phase separation in a microgravity environment.

During FY 88, a prototype unit of the hair cleansing system air/water separator was built. Several internal parts of the unit were fabricated of acrylic to facilitate the visual observation of the air/water separation process.

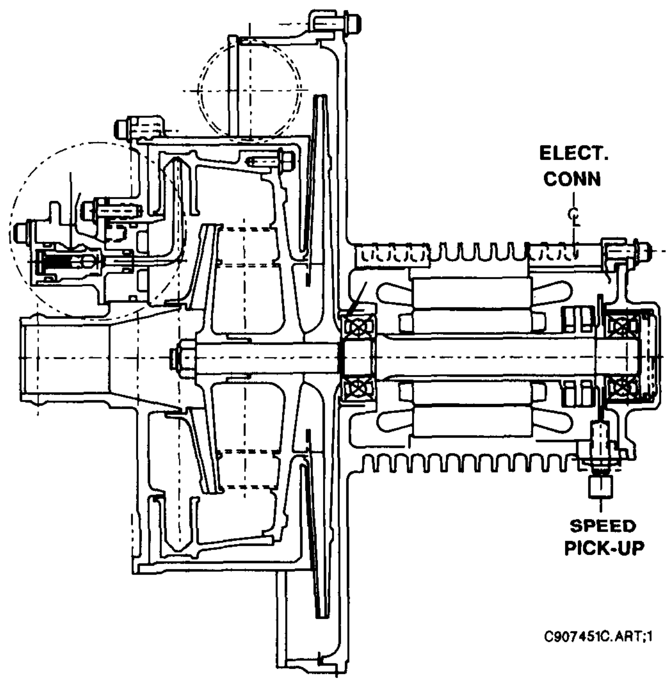
Tests were conducted in the personal hygiene laboratory to collect the baseline data (One g) to be used later to compare the performance of the unit in a micro-g environment.

Two flight tests on the KC-135, were completed and high speed film data was collected. This data is being analyzed. Results from these tests will assist the research team to identify design changes to improve the performance of the air/water separator system.

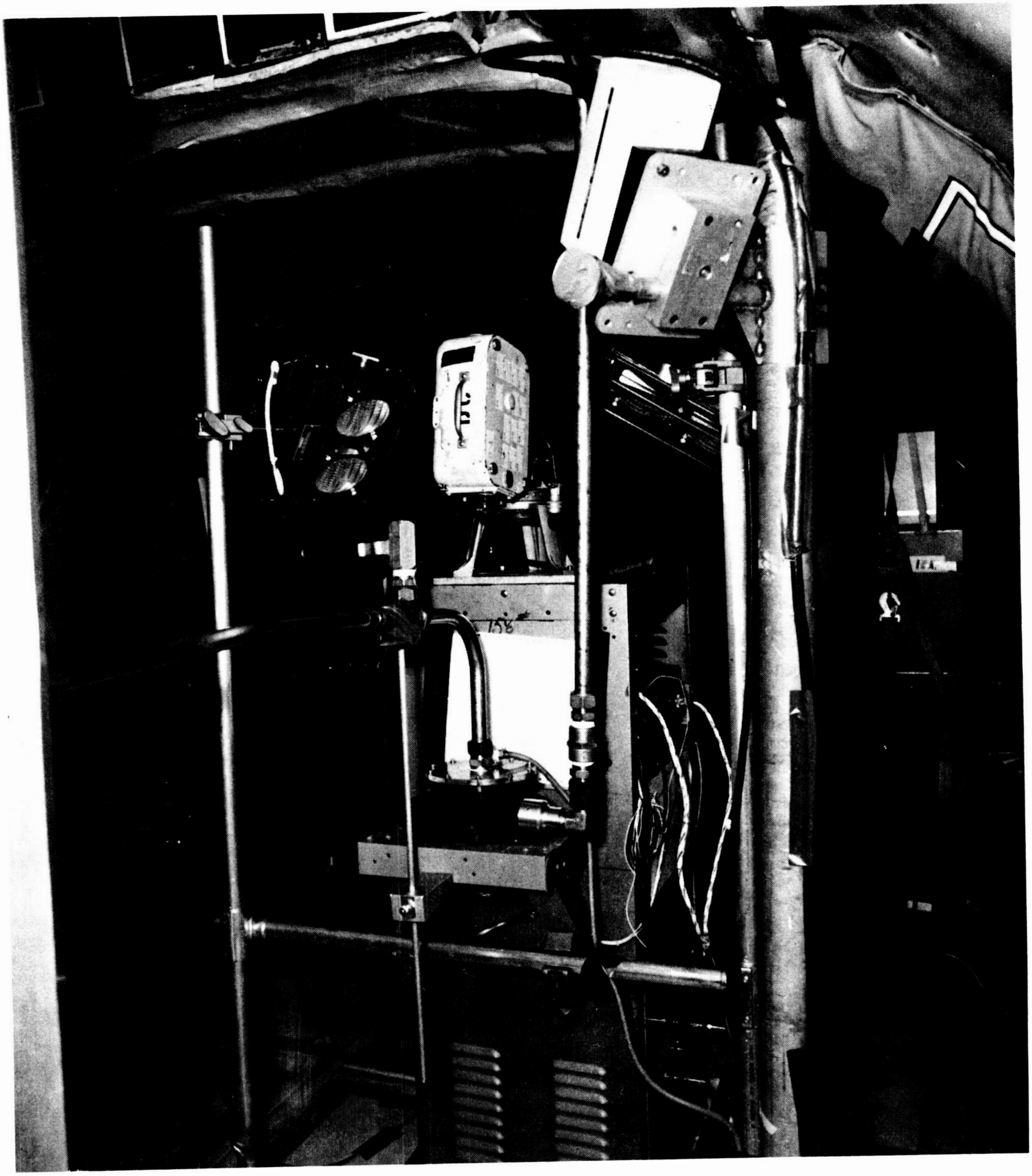
The results from this development effort could provide NASA with a new and innovative technology to address the air/water separation challenge of the future space program.




Microgravity hair cleansing system schematic.




Microgravity hair cleansing system air/water separator.



**Microgravity hair cleansing system.**

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

## Electronic Still Camera Project

**PI: H. D. Yeates/SP43**
**Reference SST 17**

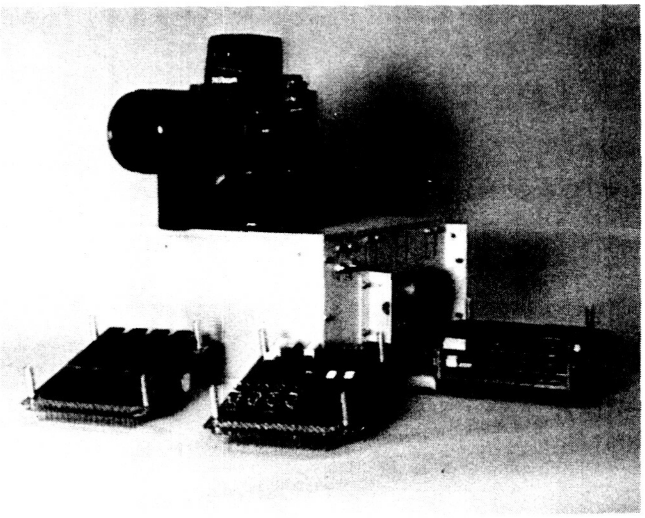
The NASA/ Johnson Space Center is currently developing an electronic still camera in which the images are stored in digital memory and then downlinked to the ground through a playback/interface unit. A monochrome breadboard camera has been developed to date with 1320 x 1035 pixel resolution coupled to a Nikon F3 camera body and an IBM PC/AT computer for data storage.

The camera was conceived to fill a void in timely ground access to near photographic-quality data obtained during space flight, especially during prolonged manned space missions, such as extended orbital, lunar and Mars missions envisioned by NASA. Many users will require photographic-quality data return more quickly than mission completion or resupply missions permit. Onboard video systems can satisfy many of the users' requirements, but high resolution requirements cannot currently be met. A high resolution imaging system which can transmit near photographic-quality images to the ground via spacecraft downlinks is needed.

The electronic still camera utilizes charge coupled device (CCD) arrays for image capture, an image storage device, lens(es), and electronics for timing, processing and recording. The completed camera system will feature (as a minimum) the following:

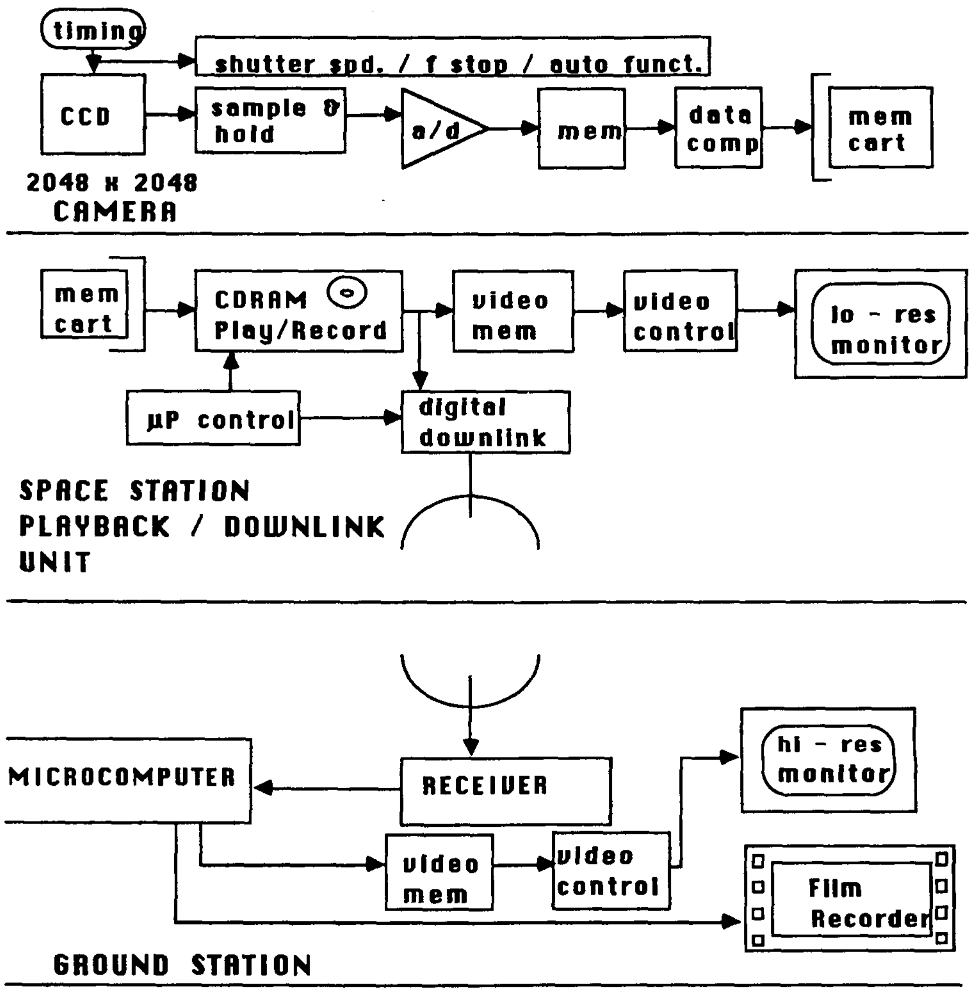
- Minimum resolution: 2048 by 2048 color (RGB) pixels
- Automatic/manual focusing
- Interchangeable lenses
- Reflex viewing with variable diopter correction
- Time/data/data recording
- Electronic flash capability
- Automatic/manual exposure control (programmable)
- Shutter speeds: 1/30 to 1/1000 sec.
- Battery operated

The electronic still camera will be completely self-contained for portability and ease of operation, thereby eliminating the need for cables or other encumbrances to the crew.



**Electronic still camera breadboard prototype.**

ORIGINAL PAGE IS
OF POOR QUALITY




Block diagram of high resolution still camera project.

## Space Station Material Evaluation Studies

**PI: James T. Visentine/ ES5**
**Reference SST 18**

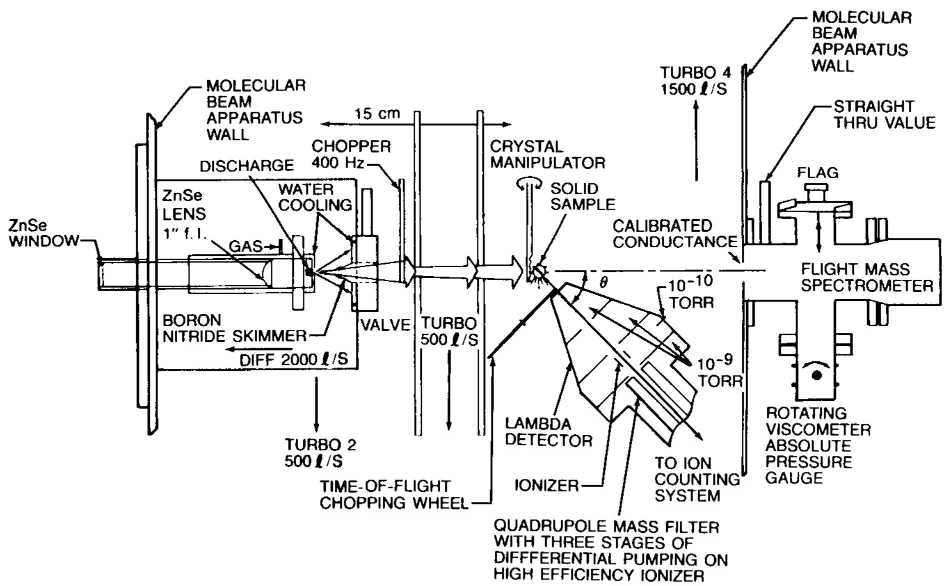
In cooperation with the Johnson Space Center, a high-energy (5 eV) atomic oxygen source has been developed by the Los Alamos National Laboratory. This source produces a well-collimated, translationally hot beam of oxygen atoms for studies involving chemical mechanisms leading to surface recession and the effectiveness of coatings designed to protect Space Station Freedom surfaces from O-atom attack. This facility utilizes a technique known as laser-sustained continuous optical discharge to produce neutral, ground-state atomic oxygen at flux levels sufficiently high ($10^{16}$ to $10^{17}$ atoms/S-cm$^2$) to enable Space Station materials and protective coatings to be evaluated for full-life performance (15-30 years) within limited periods of exposure time. A U.S. patent has been applied for and was issued this year on the source design.

Material evaluation studies are now being accomplished using 3 eV oxygen atoms produced by a high-temperature (29,100°K) oxygen-neon plasma discharge, and fluxes up to $10^{17}$ O-atoms/S-cm$^2$ have been measured within the target chamber. Atom beam composition, beam purity, kinetic energy spectra, and the vacuum ultraviolet photon flux produced by the plasma source have been characterized. The photon flux has been found to be 1 to 5 times the flux in low Earth orbit (LEO) and should contribute in a positive way to combined effects testing. To separate out the UV effects, a velocity filter will be installed to estimate photon integrations with the test specimens and narrow the energy distribution of the source.

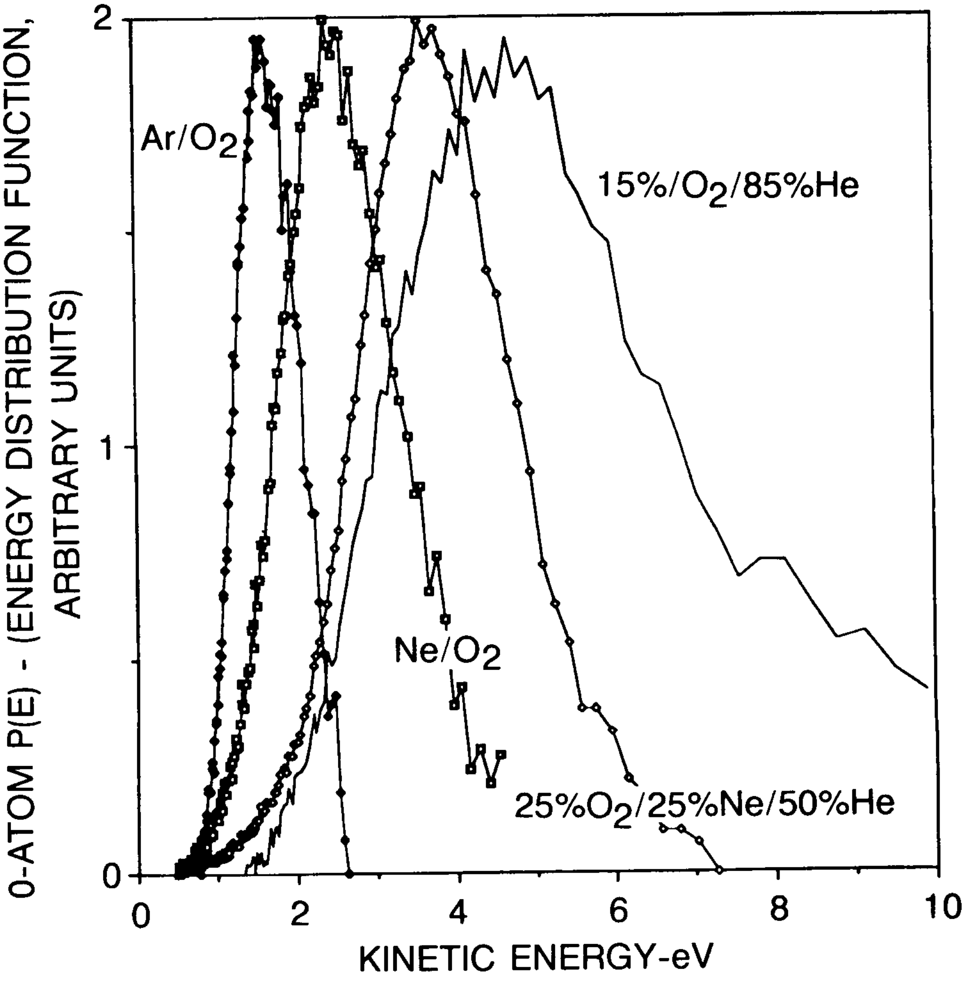
Material samples provided last year by the Lewis Research Center have been tested at Los Alamos as art of a "Round Robin" system p verification test program. Reaction efficiencies and surface damage morphologies of the LeRC sample compare favorably with the STS 8 flight results, although the reaction efficiency of FEP Teflon is somewhat high, probably as a result of vacuum ultraviolet photochemistry. A number of pumping systems have been added to the facility so that target chamber pressure of better than $10^{-9}$ torr can be achieved during the exposure studies. Surface analysis of sample materials exposed within the test region has indicated the chamber is exceptionally clean -- no silicone or fluorocarbon oil contamination was detected after the exposure studies were completed.

Several materials test projects of programmatic interest were completed during FY 1988. An extensive, though preliminary, study of oxygen-protective coating performance was completed in collaboration with the McDonnell Douglas Astronautics Company. Exposure of these coatings to atomic oxygen caused them to fail in an unexpected way, and an explanation of the failure mechanism has not been determined. The failure of protective films has important programmatic consequences for the Space Station, and additional studies will be conducted next year. In addition, the reactivity of $MoS_2$, a space-qualified, dry-film lubricant, with high velocity oxygen atoms was determined in collaboration with Sandia National Laboratories. The formation of thin oxide films and gas-phase $SO_2$ were observed, implying a limited use-life and degraded lubricating properties for $MoS_2$ films exposed to the space environment. Several fluorocarbon materials were evaluated in cooperation with McDonnell Douglas, and a particular Kel-F (polychlorotrifluroethylene) film was identified as a possible candidate for long-life service in the low-altitude space environment.

Some preliminary investigations of technology spinoff's involving LEO atomic oxygen were also completed. Low-temperature oxygen annealing of high-temperature superconductors and the production of oxide films on gallium arsenide substrates have been investigated with promising initial results. Further studies on the properties of these materials are planned for next year.




**Los Alamos atomic oxygen beam facility.**




**Atomic oxygen energy distributions for various mixtures of source gases.**

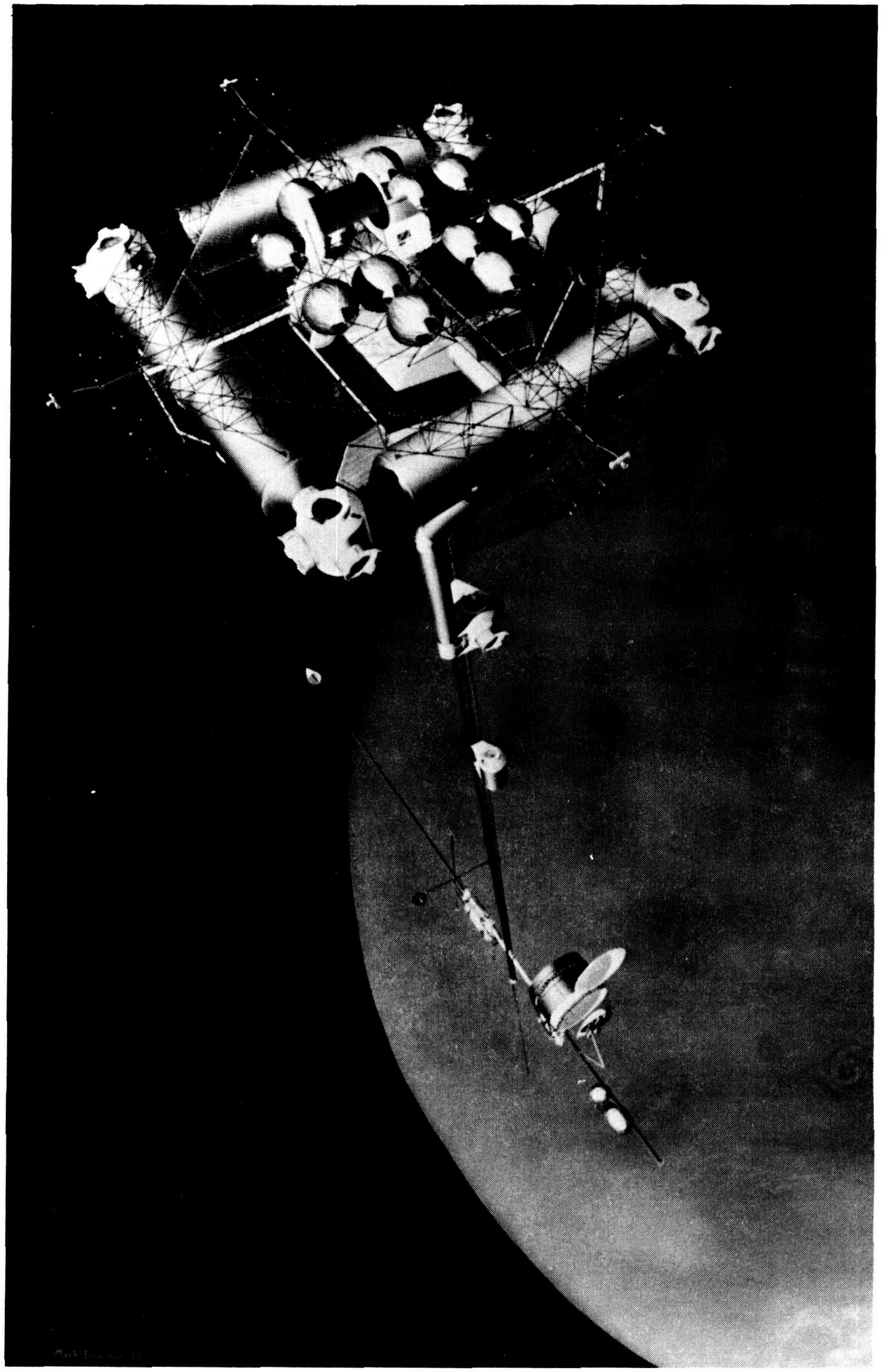
## In-flight Evaluation of the Structural Integrity of Spacecraft

**PI: John Sunkel/EH2**
**Reference SST 19**

Future spacecraft, such as Space Station Freedom, will be larger and more flexible than their predecessors. In many cases, these spacecraft will be assembled on-orbit, and they will be designed to perform missions that will extend over several years. To ensure that these spacecraft can successfully meet their performance goals, it will be necessary to periodically determine whether critical portions of the structure have been fatigued or flawed. In the event that a structural problem is detected, the Guidance, Navigation and Control (GN&C) system of the spacecraft could be reconfigured to limit operations that might jeopardize the spacecraft's ability to complete its mission. The capability to detect flaws on-orbit is especially important for a manned spacecraft such as the space station.

JSC has a research program in progress to develop and demonstrate a procedure for evaluating the structural integrity of a spacecraft on-orbit. This procedure uses the pattern of discrepancies between the analytical (modeled) and experimental (measured) values for the frequencies of a spacecraft to determine which structural elements have failed because of fatigue. The analytical frequencies will be obtained from the finite element models, and the experimental frequencies will be identified from on-orbit data.

The results and accomplishments of this research include the development and demonstration with a simple beam model of a procedure for evaluating the structural integrity of a spacecraft. A laboratory experiment has been designed to test the procedure using a "free-free" (not supported, as if in zero g) beam model . The experiment will be implemented at the Modal Analysis and Control Laboratory, University of Lowell, MA.



**Artist's concept of Mars vehicle. In-flight evaluation of structural integrity will be critical for large, flexible spacecraft structures such as this.**

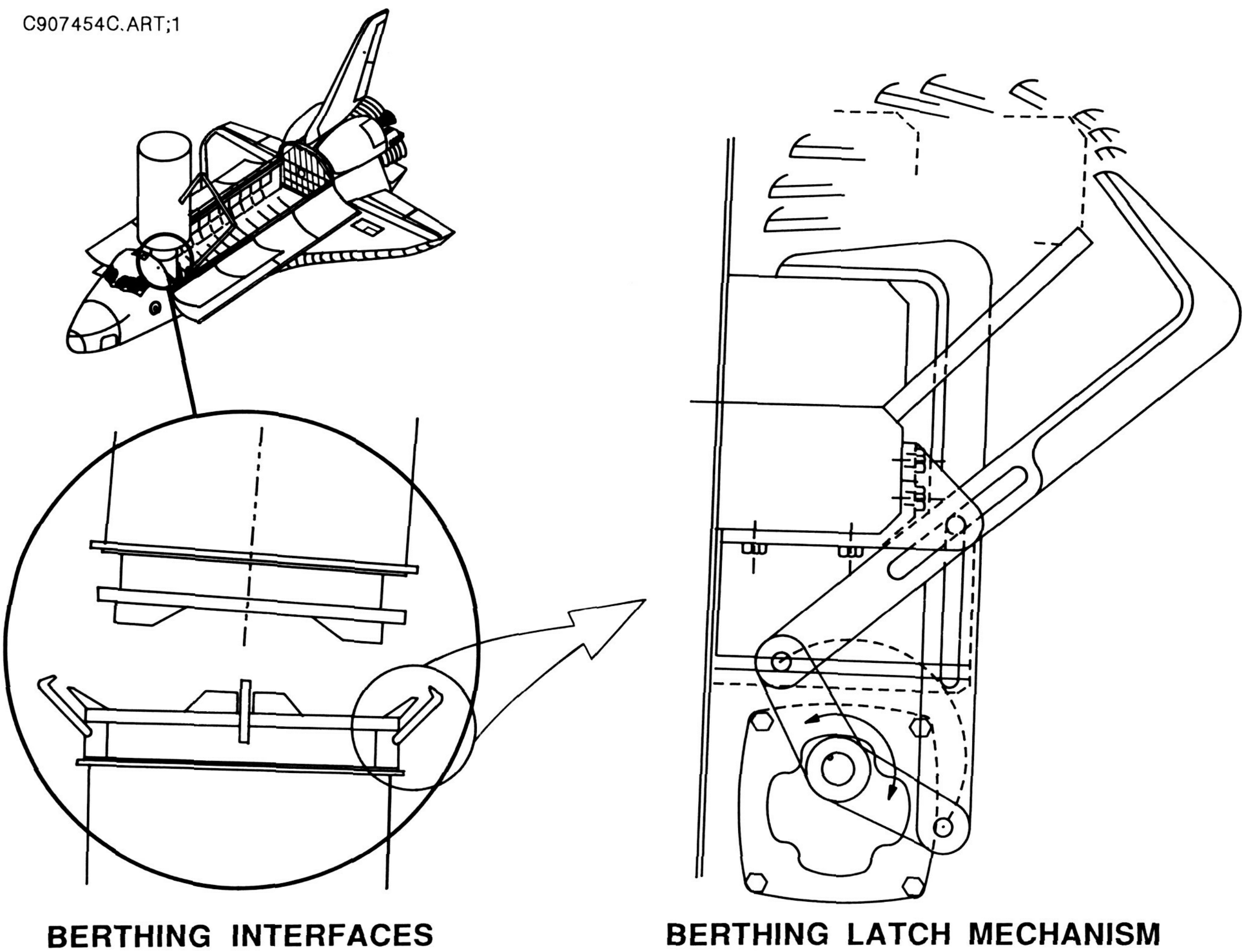
## Long-reach Retrieval Latch System

**PI: Peter M. Fantasia/ES63**
**Reference SST 20**

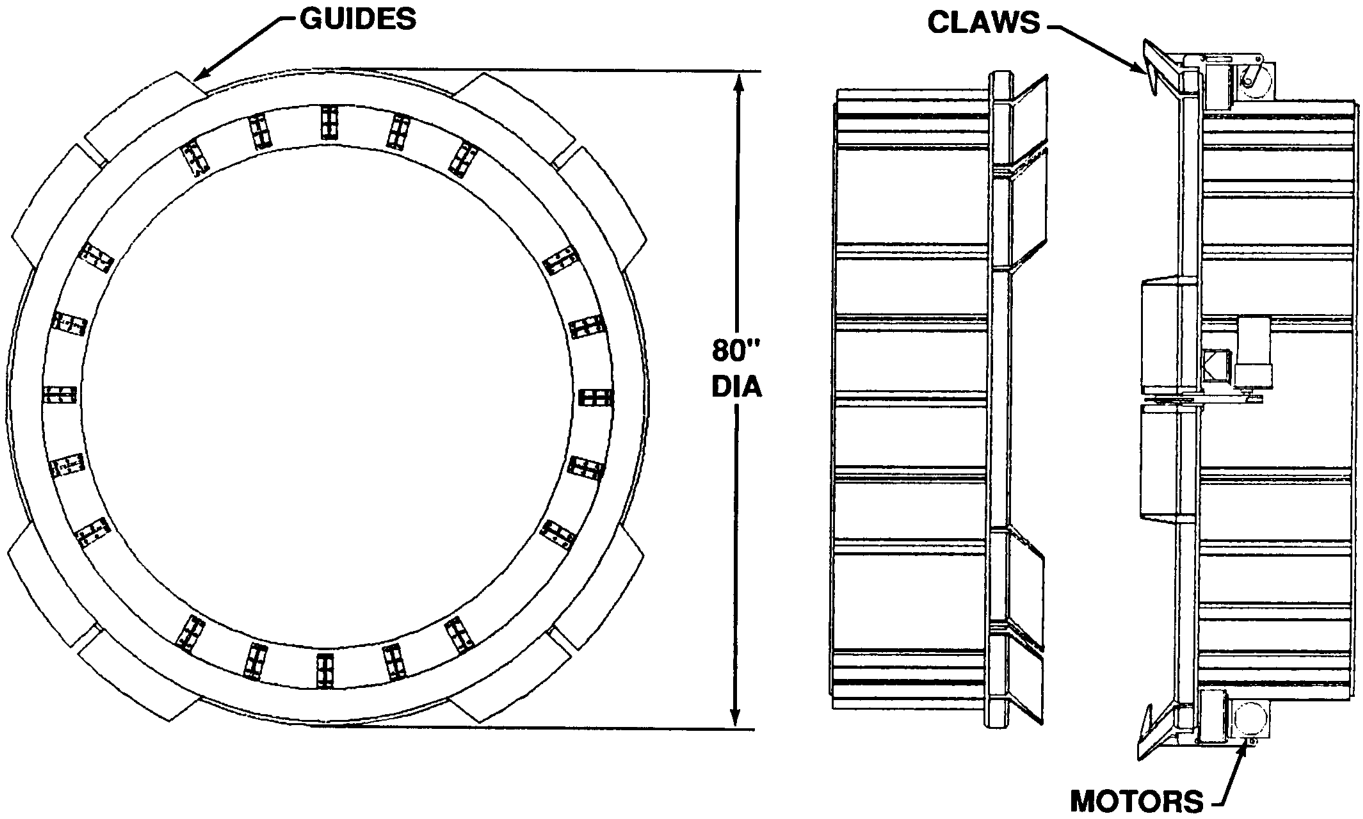
The potential need for the development of a long-reach berthing latch system was recognized in the definition phase of the Space Station Freedom Program (SSFP). A study for this system was initiated as part of the advanced technology development program for the SSFP. As a result of the study, a latch system has been developed to retrieve a pre-positioned payload or SSFP module within a 4-inch reach envelope. This envelope was established by the worst-case condition of a single joint drive operation of the Orbiter's Remote Manipulator System during Orbiter/SSFP berthing. Functional tests of the latch system have been conducted in inertially loaded conditions with 5 degree-of-freedom (roll, pitch, yaw, X, &Y) through the use of the Inertial Berthing Simulator (IBS) on an air-bearing floor.

The IBS is designed to verify the proof-of-concept of long-reach retrieval latches under kinematic and dynamic conditions. This simulator will provide the basis for the feasibility of such a concept for use in the SSFP and other future programs. Such programs would possibly use an interface alignment system, employing an androgynous ring with guides.

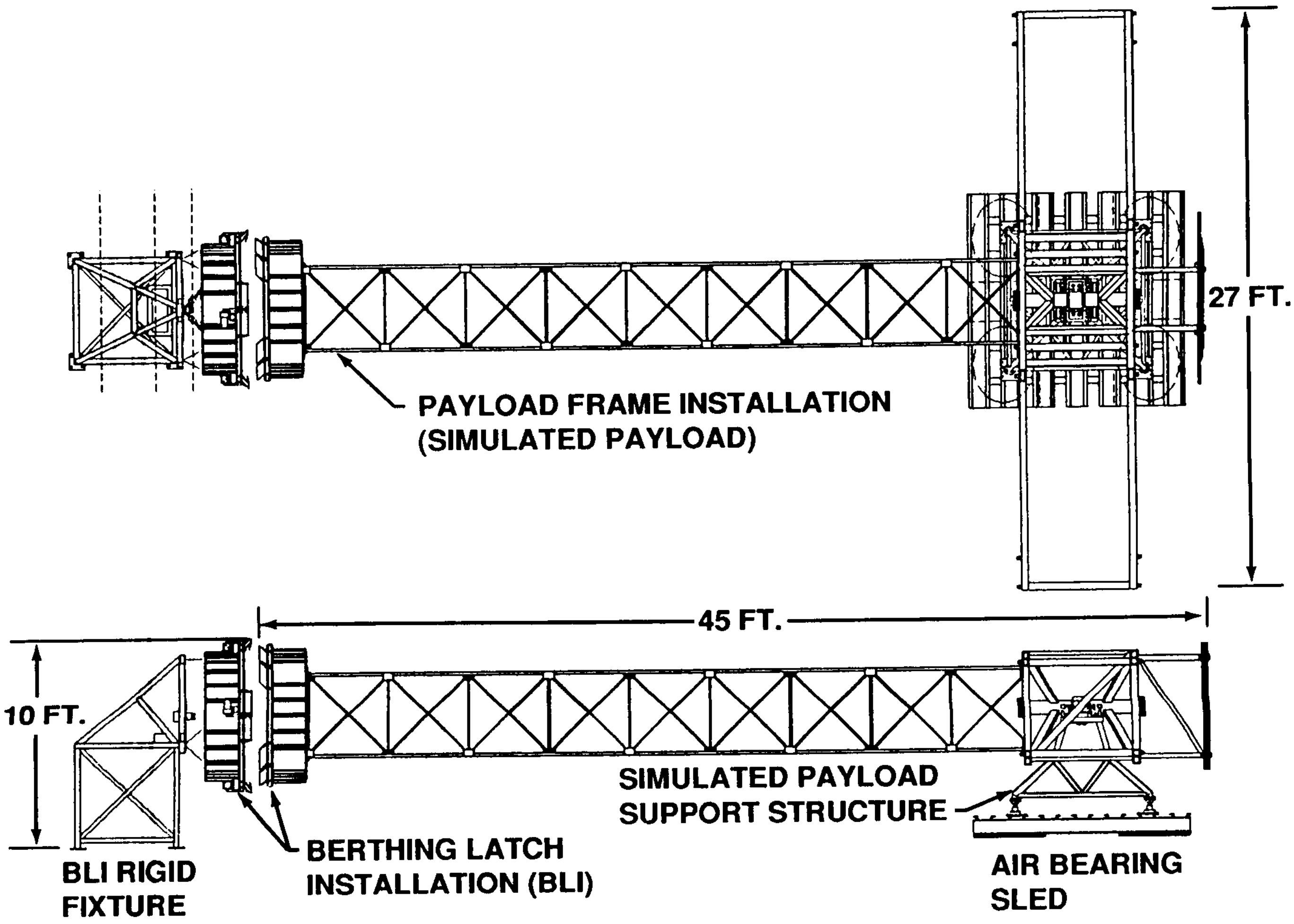
The design, fabrication, and testing of the berthing latch concept hardware and the IBS for use on the air-bearing floor has been completed. The data from the kinematic and dynamic tests of the berthing latches is being compiled and processed for analysis and evaluation. The findings and recommendations are pending the completion of the study and will be published in the test and evaluation report. The planned application of the concept is the potential incorporation of these latches into SSFP Berthing/Docking mechanisms during the development phase.




Long reach berthing latch system.




Berthing latch installation.



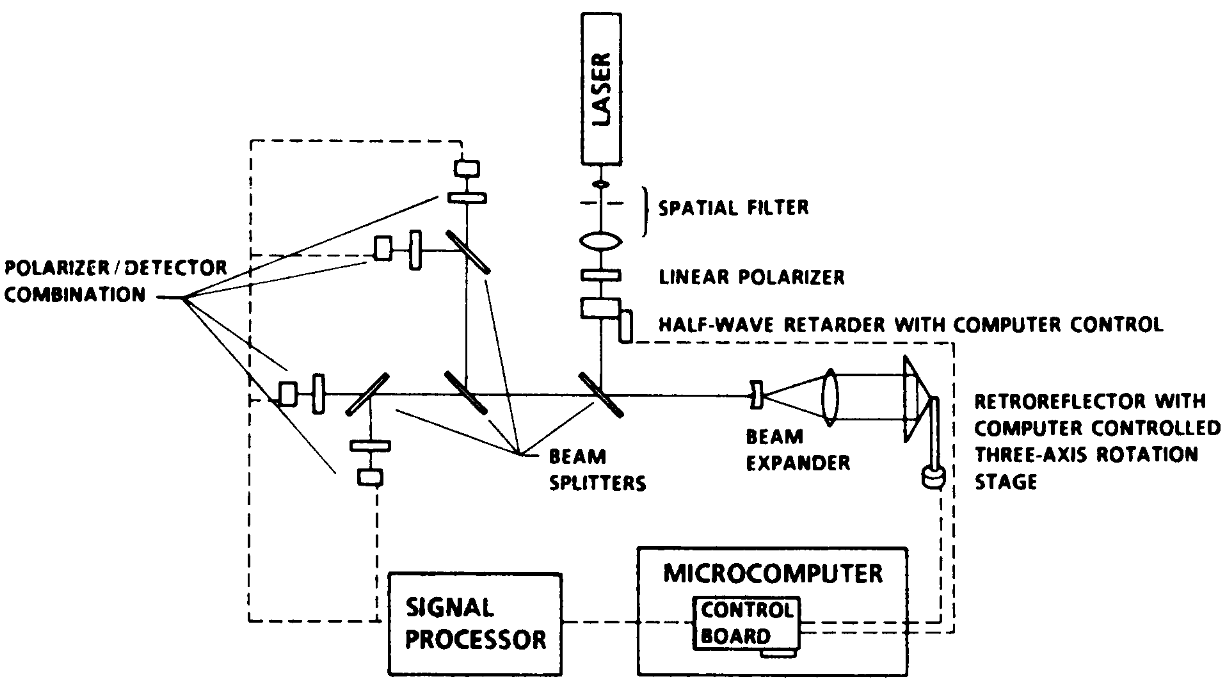

Inertial berthing simulator (IBS).

## Laser Orientation Transceiver System

**PI: R. D. Juday/EE6**
**Reference SST 22**

This is a Small Business Innovation Research (SBIR) project to develop and demonstrate a capability to determine the relative orientation (pitch, yaw, and roll) of a target on which a single unique retroreflector is mounted. This innovation has potential application to spacecraft rendezvous, station-keeping, docking, berthing, remote manipulator grappling, satellite servicing, space proximity operations, air-to-air refueling, aircraft landing systems, and industrial and commercial alignment needs.

The technique makes use of the phenomenon in which the polarization of a laser beam is uniquely modified upon retroreflection by an amount dependent on the orientation and material properties of the retroreflector. Three-axis orientation is determined by using a different material (such as gold, germanium, and molybdenum) on each facet of the retroreflector and measuring the resulting polarization shift. This technique is relatively simple, with no inherent maximum or minimum range limitations and very small size and weight scarring of the target vehicle. Accuracies within 0.3 degrees are predicted, based on phase I analyses and tests. Techniques were devised to resolve ambiguities and regions of high error by using two different transmit polarizations. A deliverable three-axis prototype is proposed for phase II.




**Schematic diagram of the transceiver system.**

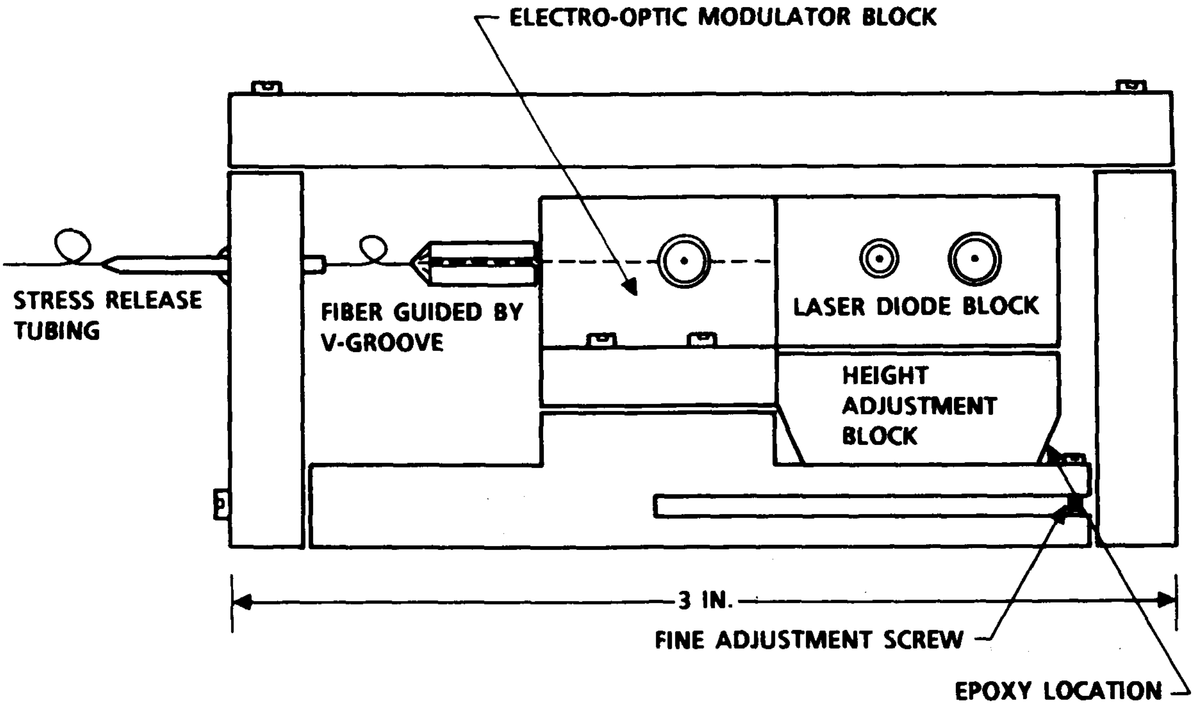
## Tunable Laser Diode and Optical Phase-Locked Loop

**PI: K. F. Dekome/EE6**
**Reference SST 23**

This is a Small Business Innovation Research (SBIR) project to develop and demonstrate a Tunable Laser Diode (TLD) in a precise, rugged unit. A commercially available laser diode will be integrated with specially fabricated electro-optic modulators (EOM's) and focusing and alignment optics to form the TLD. The EOM's will effectively modulate the length of the laser cavity under electronic control, thereby modulating the wavelength of the laser output. It is expected that tuning ranges of 400 Å (16,000 GHz) will be realized.

The TLD package will then be integrated into an optical phase-locked loop (OPLL) assembly. The OPLL is the basic building block in constructing narrow linewidth frequency synthesizers and coherent detectors. Using a mixture of commercially available and fabricated optical and microwave mixers and amplifiers, a phased-locked loop arrangement will be constructed and the loop performance quantified and documented.

This research and development work will have a direct impact in areas of NASA interest such as range/range-rate lidars, optical frequency modulation communications, fiber-optic gyroscopes, optical wavelength synthesizers and radiometers, and optical frequency hopping for long-range secure communications.




Sketch of tunable laser package (side view).

## Space Station Fiber Optics Intermediate Frequency Distribution Breadboard

**PI: N. A. Olson/EE3**
**Reference SST 24**

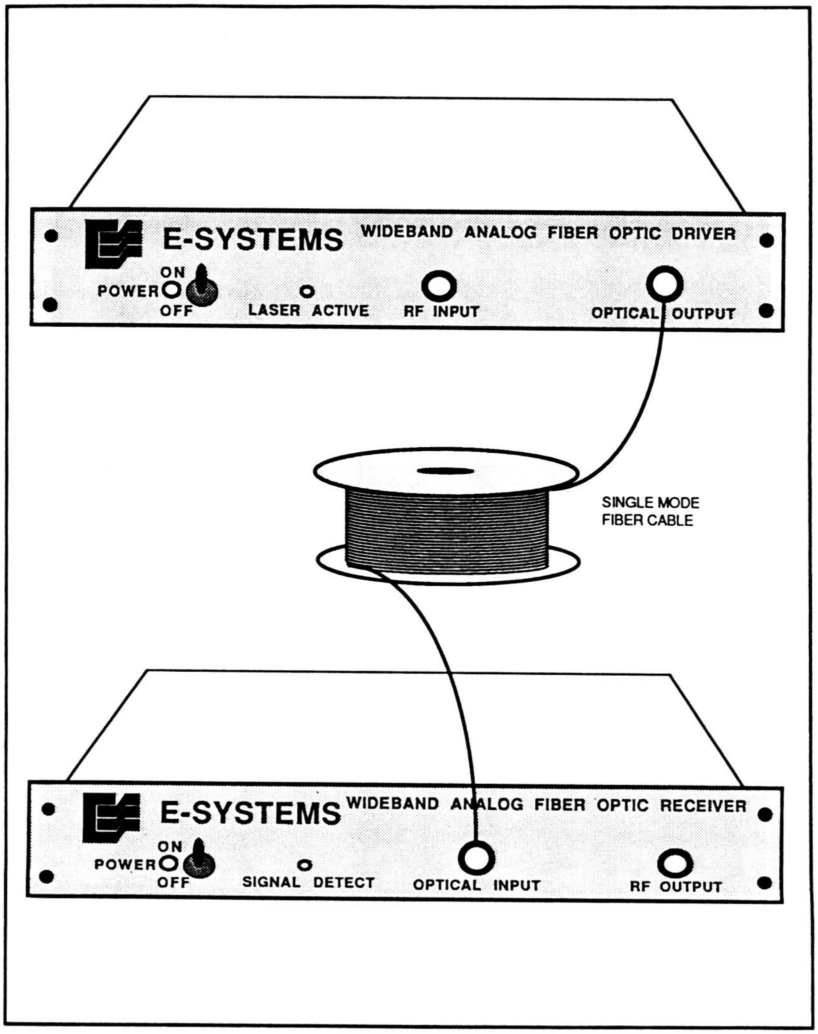
In the Space Station space-to-space communications system, part of the signal-handling hardware is mounted close to the antennas on the truss structure in order to minimize power loss in the high-frequency Ku-band. Other components are mounted within the Space Station node modules for a more protected environment. To transmit signals between the node equipment and the antenna-mounted equipment, the frequency must first be down-converted to a lower intermediate frequency in the UHF band which is easier to distribute and work with and which sees less power loss.

The objective of this effort was to build a fiber optics intermediate frequency distribution breadboard, compatible with the Space-to-Space Communications Base Station breadboard, which would distribute (transmit) signals between the UHF portion of the breadboard and the Ku-band portion of the breadboard. This breadboard will be used to evaluate the performance of fiber optics as a possible media in the Space-to-Space Communications Subsystem for distributing UHF signals between the antenna-mounted equipment on the truss and the equipment in the node modules of Space Station.

In communications, a "link" is said to exist between the transmitter and receiver.

E-Systems designed and built an analog fiber optics link using a laser diode to transmit multiple UHF signals. In this particular link, a laser diode is the transmitter, a pin diode is the receiver, and fiber optics is the transmission medium. Analog refers to the method of modulating (varying) the laser intensity to correspond to the radio frequency signal which is to be converted and transmitted. The breadboard can be used on the transmit or receive link of the Base Station Breadboard. The breadboard has been delivered to JSC, and, during FY89, tests using the breadboard in the Space-to-Space Test Bed will include intermodulation distortion and adjacent channel interference tests. Additionally, tests with added optical loss will be performed on the breadboard to evaluate its performance with up to 11 optical connections.

The advantages of using fiber optics are the low weight of the cable and the low power loss associated with the cable.




**Broadband analog fiber optic test link.**

## Space Station's Near Field Antenna Test Facility

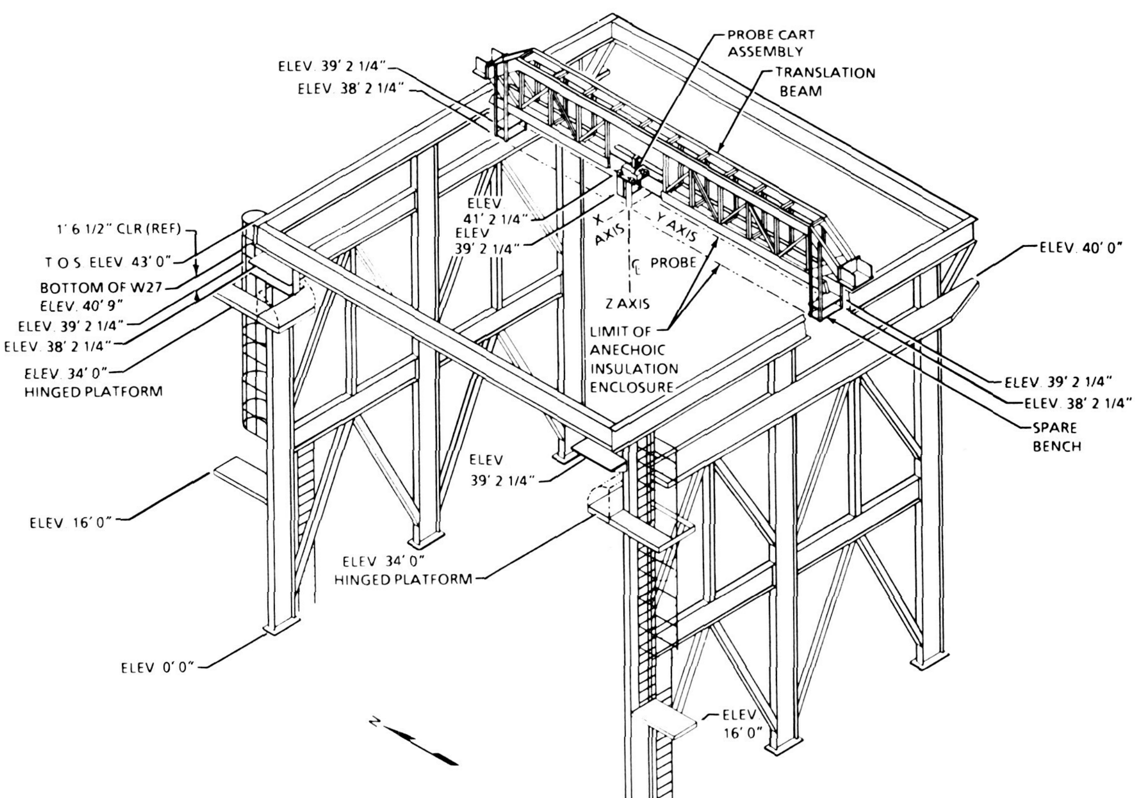
**PI: J. Ngo/EE3**
**Reference SST 25**

The JSC Anechoic Chamber has been used extensively in development of the Apollo and Space Shuttle Orbiter antennas. However, the chamber cannot accommodate measurements of larger Space Station antennas because the separation distance between the source and the test antenna is inadequate. Therefore, the chamber has been modified to a configuration called the Near Field Antenna Test Facility. The purpose of this facility is to measure antenna characteristics at close range and transform the data to far field (useful) patterns using the Fast Fourier Transform (FFT) algorithm. The near field scanner measurement system consists of a translation beam moving in one direction (X-axis) and a probe moving in a perpendicular direction (the Y-axis). The system is used to measure an antenna's near field radiation patterns as a function of X and Y rectangular coordinates.

The objectives of this effort are: (1) designing and interfacing a Laser Transducer System with the near field scanner measurement system, (2) software development for data acquisition and analysis, and (3) overall system integration.

An overall system has been designed and developed. A laser system was designed and will be installed on the structure and translation beam. Laser and position control system software has been developed. A radio frequency (RF) receiver was designed and fabricated and synthesizer microwave operation control routines were developed. Network analyzer system control routines were written. An experimental probe correction algorithm was developed to correct and substantiate measured probe pattern data in order to determine the antenna performance. Installation of all software on the HP-1000 computer system was completed.

System integration including the Laser Transducer System, RF receiver system, laser alignments of the translation beam and the probe, and hardware and software control algorithms will be performed in the first part of 1989.




**Proposed near field antenna test facility.**

ORIGINAL PAGE IS
OF POOR QUALITY

## Extravehicular Mobility Unit Backpack Antenna System

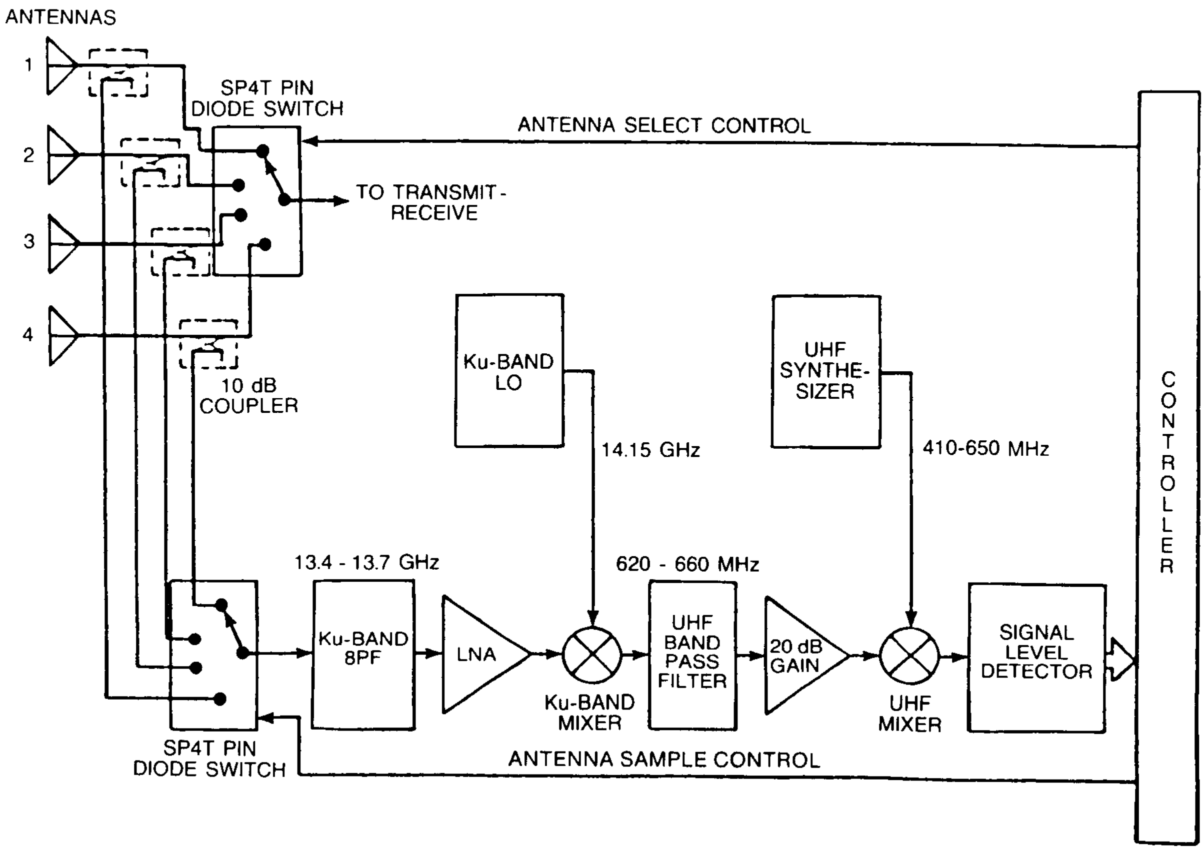
**PI: J. Ngo/EE3**
**Reference SST 27**

During periods of extravehicular activity, crewmembers of Space Station Freedom must be able to communicate with the Space Station regardless of their location and orientation. Therefore, a communication link with full spherical coverage is desired.

The objective of this in-house task was to study candidate antennas which have a wide beamwidth, circular polarization, and can be flush-mounted on the Extravehicular Mobility Unit (EMU) backpack. Another objective is to optimize mounting locations of antennas on the backpack for a spherical coverage and for a minimum number of antennas.

Four different types of antennas have been fabricated and tested. A complete radiation distributed pattern (RDP) of Archimedian spiral antennas mounted at four locations on the EMU backpack was taken and analyzed. An RDP is a graphic representation of the radiation properties of an antenna as a function of space coordinates. Radiation properties include radiation intensity, field strength, and polarization. Results indicate conical-log spiral antennas are the best candidates.

A switching system was also developed to switch signals between four antennas. This included design and fabrication of two switches, KU-Band electronics, and development of control algorithms. Using a communication system and camera, the switching system will be evaluated to determine the quality of signals.




**EMU antenna switching system.**

## Preliminary CERV Antenna Analysis

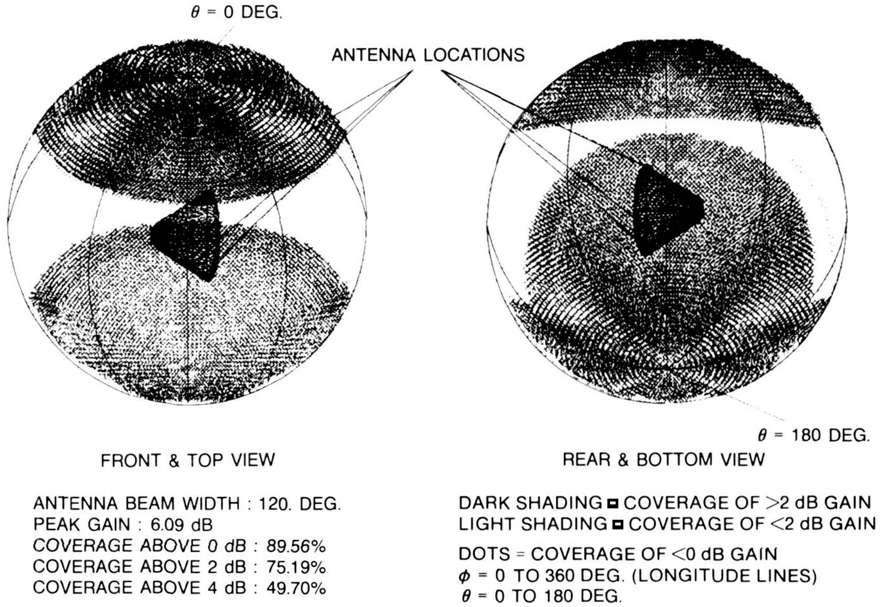
**PI: J. A. Cook/EE3**
**Reference SST 28**

CERV or Crew Emergency Return Vehicle is a space vehicle that will 1) return an entire crew in an emergency situation, 2) return an entire crew in a planned situation, and 3) return an injured crewmember from the Space Station safely to Earth. The CERV may also be transferred to the space station via an expendable launch vehicle (as opposed to using the Space Shuttle).

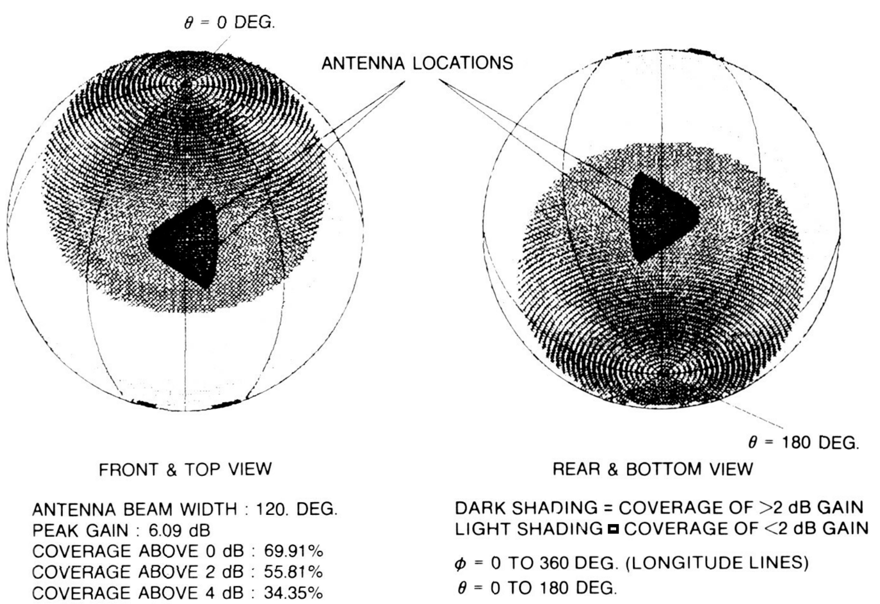
The purpose of antenna analysis at this level is to determine the number required, location of the antennas, and how they will perform around other objects, i.e., the Space Station. The first part of the analysis procedure is to perform obscuration studies, that is, to find out what part of the field of view is blocked by the CERV structure itself, or by any surrounding objects. The second half of this study is to look at the simulated radiation (or coverage) pattern for a standard omni antenna mounted at the selected antenna locations.

This task developed the initial S- and L-band antenna analysis for the Apollo type CERV Phase-A study. Accomplishments in FY88 include 1) obscuration and coverage patterns of various L-band antenna configurations, 2) obscuration and coverage patterns of various S-band antenna configurations, 3) S-band and L-band antenna patterns with the CERV located at various locations around the Space Station, for example, just leaving, ten minutes later, etc. Also analyzed were the Global Positioning System (GPS) satellite locations which showed whether there were at least four satellites in view (needed for the GPS system to work) (or that the station does not block more than the required four), and 4) publication of a technical report.

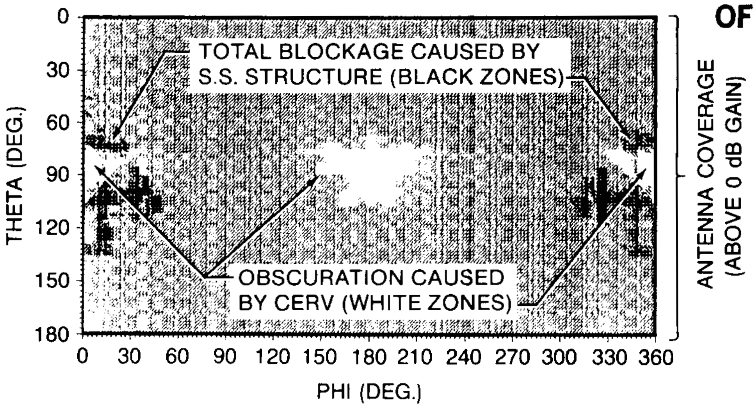
With this information - a model of the CERV configuration and type of frequency band - we were able to determine the number of antennas, the position of the antennas and the expected radiation patterns of the overall S-band and L-band antenna configuration.

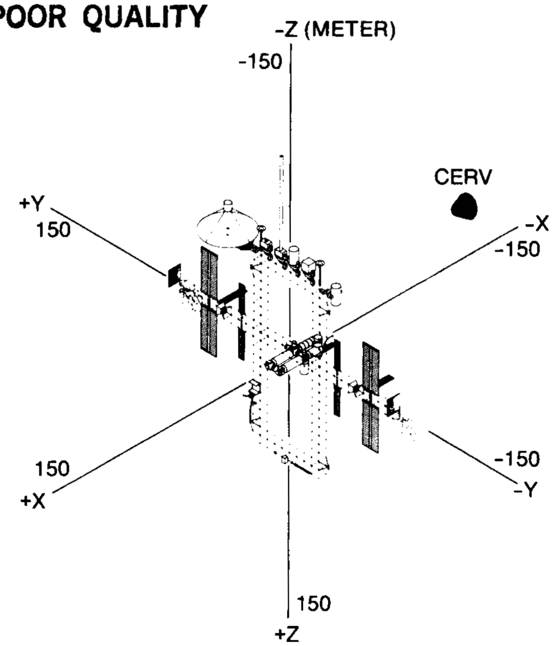



**One side of the CERV with a fictitious sphere around it. This sphere shows the coverage plot of the CERV with 3 S-Band antennas.**




**The sphere in this figure shows the coverage of the CERV with 2 S-Band antennas.**

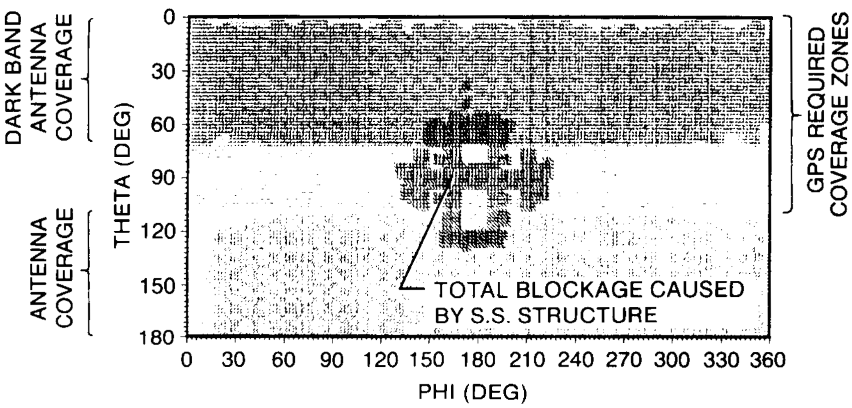


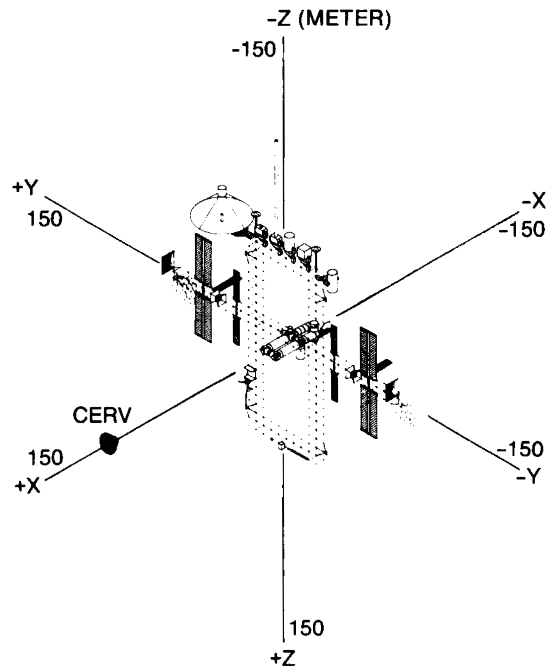




ANTENNA BEAMWIDTH : 120. DEG.
PEAK GAIN : 6.09 dB
CERV POSITION (IN S.S. COORDINATES) :
X = -100. METERS
Y = 0. METERS
Z = -20. METERS

ANTENNA COVERAGE ABOVE 0 dB GAIN : 89.56%
TOTAL SPACE BLOCKAGE CAUSED BY S.S. STRUCTURE : 5.50%
ANTENNA COVERAGE BLOCKED BY S.S. STRUCTURE : 3.95%

**CERV antenna obscuration with 3 S-band antennas.The CERV in an arbitrary position around Space Station Freedom. The first CERV is located (in station coordinates x,y,z ) at -100, 0, -20 meters. The antenna coverage above 0 dB at this distance from the Space Station is 89.56 percent.**




ANTENNA BEAMWIDTH : 100. DEG.
PEAK GAIN : 6.68 dB
CERV POSITION (IN S.S. COORDINATES) :
X = 100. METERS
Y = 0. METERS
Z = 0. METERS

ANTENNA COVERAGE ABOVE 0 dB GAIN : 60.61%
TOTAL SPACE BLOCKAGE CAUSED BY S.S. STRUCTURE : 9.56%
ANTENNA COVERAGE BLOCKED BY S.S. STRUCTURE : 4.00%
TRANSMISSION PATH BLOCKED BY S.S. STRUCTURE : 12.36%

**CERV antenna obscuration with 2 L-Band antennas.The second CERV is located at 100, 0, 0 meters. The coverage above 0 dB here is 60.61 percent.**

## Control Zone Antenna System Development

**PI: J. S. Kelley/EE3**
**Reference SST 26**

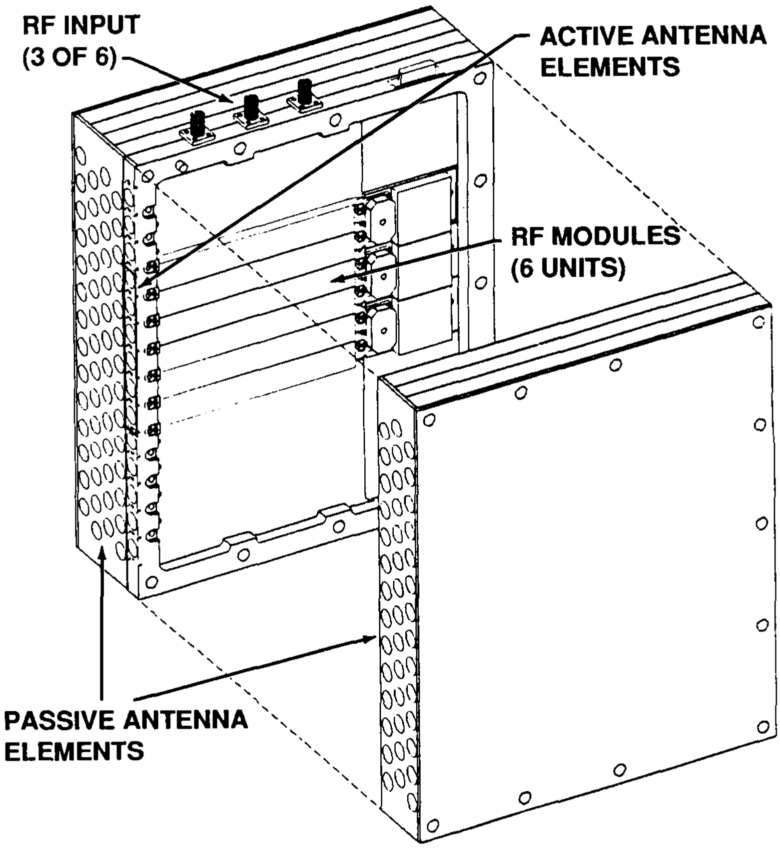
The objective of this task is to demonstrate technology required to support Space Station Freedom communications requirements within the "Control Zone" range of 1 to 20 nautical miles. Communications are required with multiple users simultaneously; six links are baselined for this development effort.

An antenna array breadboard was designed in FY86 which could demonstrate the capability of a multichannel-phased array utilizing Monolithic Microwave Integration Circuit (MMIC) technology. The breadboard design consists of a transmitting array, a receiving array and a beam steering controller. The receiving array contains six active elements. Each element contains two small signal amplifiers and six phase shifters. A controller for the phase shifters is shared by pairs of radio frequency (RF) elements. The transmit array elements are identical to the receive elements with the exception that a 50 milliwatt power amplifier is added to increase output power.

The FY87 effort was devoted to the fabrication of the breadboard hardware and verifying the performance of the individual assemblies. The important developments for this effort are the gallium arsenide chips which are used for the distributed amplification and the phase-shifting circuits. The breadboard uses 72 phase-shifter chips, 24 small amplifier chips and 6 power-amplifier chips. Silicon digital circuits are employed for element controllers and phase-shifter drivers. Microstrip networks are used for signal routing and for power division.

The FY88 effort of assembling and checking out the breadboard has been extended to minimize cost. Time consuming difficulties were encountered in integrating "off the shelf" personal computer adapter cards and software routines to control beam steering and mode control. Some difficulties were also encountered in integrating the RF modules into the array.

The breadboard hardware will be evaluated in system test at JSC in FY89. The system test will be concentrating on the effects of multiple communication links through the breadboard array.




**Transmit array breadboard.**

## Implementation of a Facility for Integrated System Testing Using Artificial Intelligence Techniques

**PI: Henry S. Chen/EE8**
**Reference SST 29**

In light of communications technology advancements over the past decade, new systems are operating with low bit error rates and are robust in the presence of channel anomalies. While robust systems are naturally desirable in practice, they may pose problems to development engineers who rely on the computer modeling of system performance. This is especially true for the Monte Carlo simulation techniques which often require unacceptably large computer time expenditure. Therefore, a new approach to simulate communication systems accurately and efficiently is required. This project is sponsored by the National Aeronautics and Space Administration under the Small Business Innovation Research program. By working with Stanford Telecommunication, Inc., the agency is sponsoring the development of new efficient simulation algorithms to facilitate communication engineers in their analysis and design of complicated systems.

This research effort centered on developing and implementing efficient simulation techniques which provide similar accuracy of the Monte Carlo techniques but with less computer time expenditure. Toward this end, the Facility for Integrated Systems Testing (FIST) modeling software was developed to provide four alternative efficient estimation techniques to the Monte Carlo method. An expert system shell was provided to assist the engineer in selecting the technique which most appropriately fits the system to be modeled. This effort has demonstrated the potential applicability of FIST to the Space Station Freedom modeling process. The incorporation of an expert support system has laid the groundwork for more possible follow-on activity, such as the integration of other modeling tools into the FIST framework, thereby streamlining the current modeling procedures.

## Algorithm Development for the Coordinated Control, Including Dynamics and Forces, of a Payload Utilizing Multiple Manipulator Arms

**PI: Gerald J. Reuter/EF2**
**Reference SST 30**

The overall objective of this Phase II Small Business Innovative Research effort is to define the manipulator system and to develop and test the necessary control theory and algorithms for the coordinated control, including the capability of managing dynamics and forces, of a payload by two manipulator arms. The detailed technical objectives are:

- The definition of manipulators to be targeted for a full scale hardware test bed
- The definition of manipulator modifications necessary for the defined coordinated manipulator control
- The control computer and electronic hardware definition for the defined coordinated manipulator control
- The definition of the method of teleoperator and robotic control for the multiple manipulators
- Coordinated manipulator control algorithm development for:
    - Coordinate transformations for payload reference control
    - Hybrid position-force loops for managing the forces carried through the payload
    - Force sharing for gravity, inertial, and other external loads
- Algorithm and software development for manipulator system modeling and computer simulation
- Implementation of the coordinated manipulator control algorithms on the computer for simulation, testing, and debugging
- A system demonstration of the control algorithms' function and of their ability to be implemented and have a processing rate corresponding to real time.

The manipulator arms targeted for this effort are the Robotics Research K-1607 and K-2107, housed in the Advanced Systems Development Laboratory at the Johnson Space Center. The following software tools were selected for this effort:

- SD/Exact was selected for the dynamics.
- Advanced Continuous Simulation Language (ACSL) was the control simulation software selected.
- ProMatlab was the control analysis software tool selected.
- Robcad was selected for the kinematic and animation representation.

The Teleoperation/Robotic control definition task was completed. Animation software development is 85 percent complete. The control algorithm design/analysis and the simulation software development are 60 to 70 percent complete. The effort is scheduled for completion in July 1989. Follow-on activity will involve the hardware implementation in the Advanced Systems Development Laboratory.

Development of two manipulator arm systems will have application in Space Station and on the Flight Telerobotic Servicer (FTS).

## Thermal Expert System Integration

**PI: Thomas Pendleton/EF5**
**Reference SST 31**

Based upon a Congressional mandate to NASA to advance automation technologies for Space Station Freedom and for terrestrial applications, the Office of Aeronautics and Space Technology (OAST) initiated the Automation and Robotics Program to develop new core technologies in this area, to demonstrate their applicability to programs of interest to NASA, and to transfer this technology, through training and support activities, throughout the Agency. A major element of the A&R Program is the Systems Autonomy Demonstration Project (SADP). The objectives of this project are to:

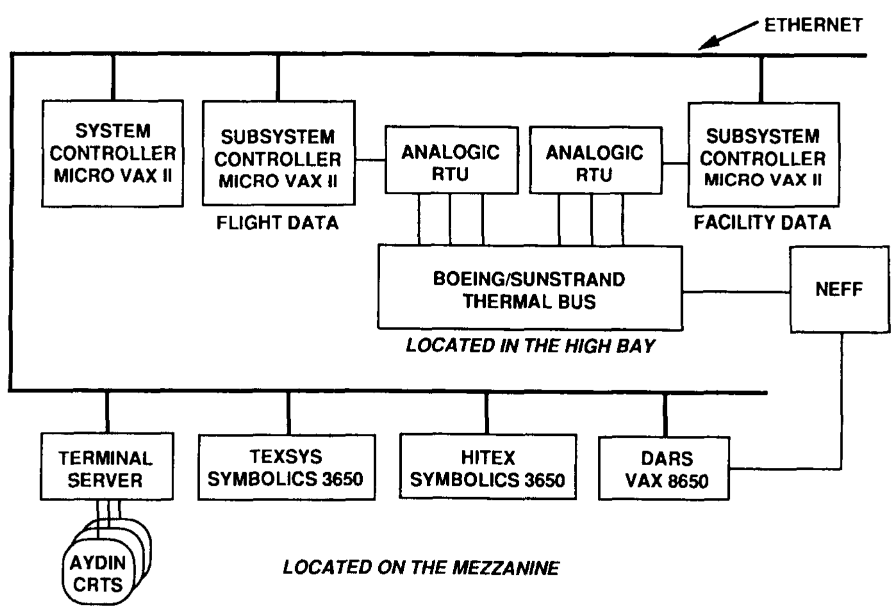
- Develop tools and trained personnel for AI technology transfer
- Provide a technology focus for automation R&D supporting NASA missions
- Provide a technology focus for validation and demonstration of automation technology prior to transfer to programs
- Support the acceptance of automation inside NASA
- Support the acceptance of NASA AI work within the international AI community.

Under the auspices of the SADP, a series of four demonstrations will be conducted to show the capability of increasingly complex expert systems applied to Space Station Freedom Subsystem Test Beds. The first of the SADP demonstrations, the Thermal Expert System (TEXSYS) demonstration, is being developed for a Prototype Space Station Freedom Thermal Bus System on the Space Station Freedom Thermal Test Bed at JSC. TEXSYS will be used to monitor, control and diagnose the Boeing Aerospace Prototype Thermal Bus System (BATBS), which is a ground-based engineering model of a possible Space Station Freedom active thermal control system.

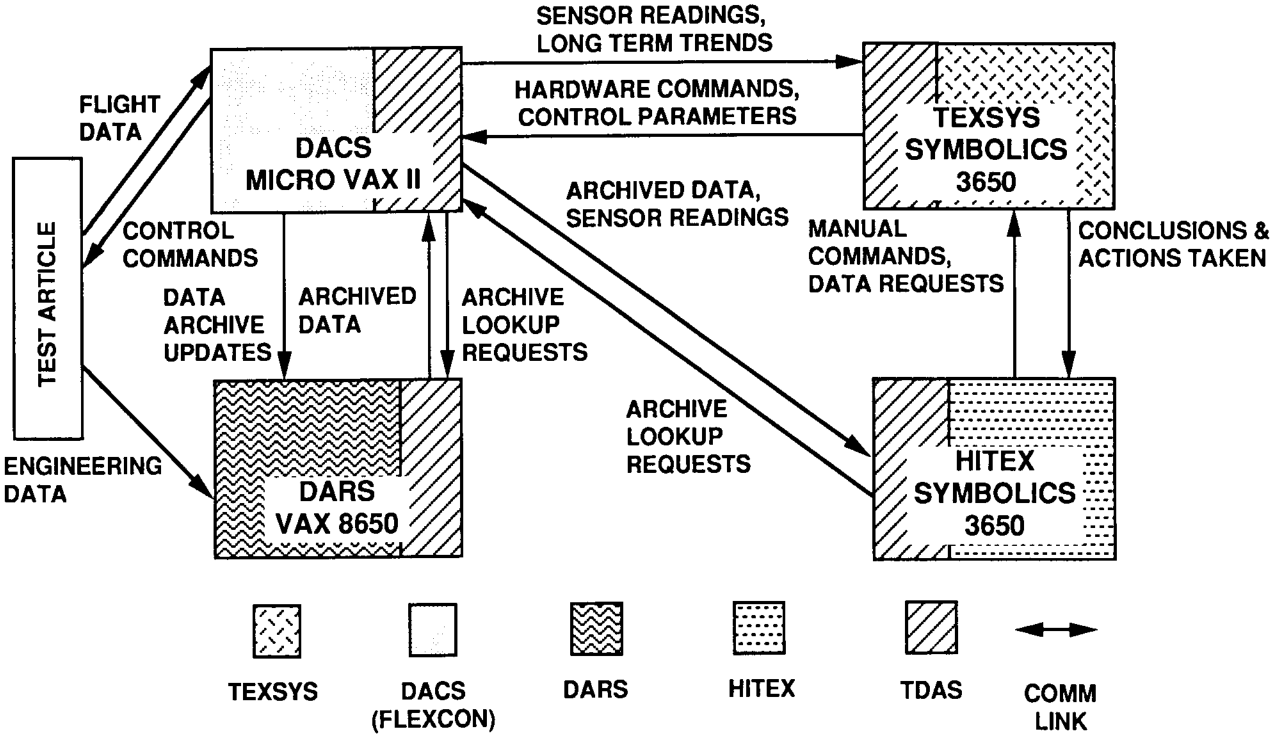
The TEXSYS expert system resides in one of two Symbolics 3650's; the other 3650 hosts HITEX, the human interface for the expert system. These two software systems are under development at Ames Research Center (ARC). A commercial system, FLEXCON, is being used for the System and Subsystem controllers, running in MicroVAX II's, and for the Data Archival and Retrieval System (DARS). The FLEXCON based system controller software is called the Data Acquisition and Control System (DACS).

The Thermal Expert System Integration project is to design, build, test, and implement the software which connects TEXSYS and HITEX with the DACS and DARS software and to carry out the integration of the FLEXCON, TDAS, and TEXSYS on the test bed. This integrating software is called the TEXSYS Data Acquisition System (TDAS), and resides in the various test bed computers. The interface between TDAS and FLEXCON has been determined by the procedure calls that the FLEXCON system makes available to the user. The interface between TDAS and the TEXSYS and HITEX systems has been defined in an Interface Control Document (ICD) which specifies each of the functions which one can call upon the other to perform. The ICD defines the timing and format of the functions, which perform requests and data transfers, and the design of the interface software. This software is now complete and will be used in the coming year to carry out the total system integration as defined in the Software Test and Integration Plan (STIP).

The purpose of the STIP is to define tests to ensure that the expert system meets the requirements stated in the TEXSYS System Requirements Document (SRD) and ICD and to define tests to provide a measure of TEXSYS' level of performance in its operational setting. The plan is applicable to that sequence of tests performed subsequent to the delivery of the final TEXSYS system from ARC and prior to the formal TEXSYS demonstration which also is planned for the coming year. Plans for follow on demonstrations are currently being developed and refined.




**Hardware layout for JSC building 32.**




A diagram showing software allocation.

## CONFIG Tool: Qualitative Models and Discrete Event Simulation for Failure Analysis and Fault Management

**PI: Jane T. Malin, EF5**
**Reference SST 32**

A critical technology area for future man-machine aerospace systems is artificial intelligence and expert systems for aiding monitoring, diagnosis and management of degraded performance, faults and failures. Like expert engineers, such systems should be able to use partial information to identify likely causes of system problems and to select reasonable tests and control actions. Expert system software can and should be developed while the monitored system is being developed. The goal of this project is to develop and demonstrate technology to support timely development of this critical type of software.

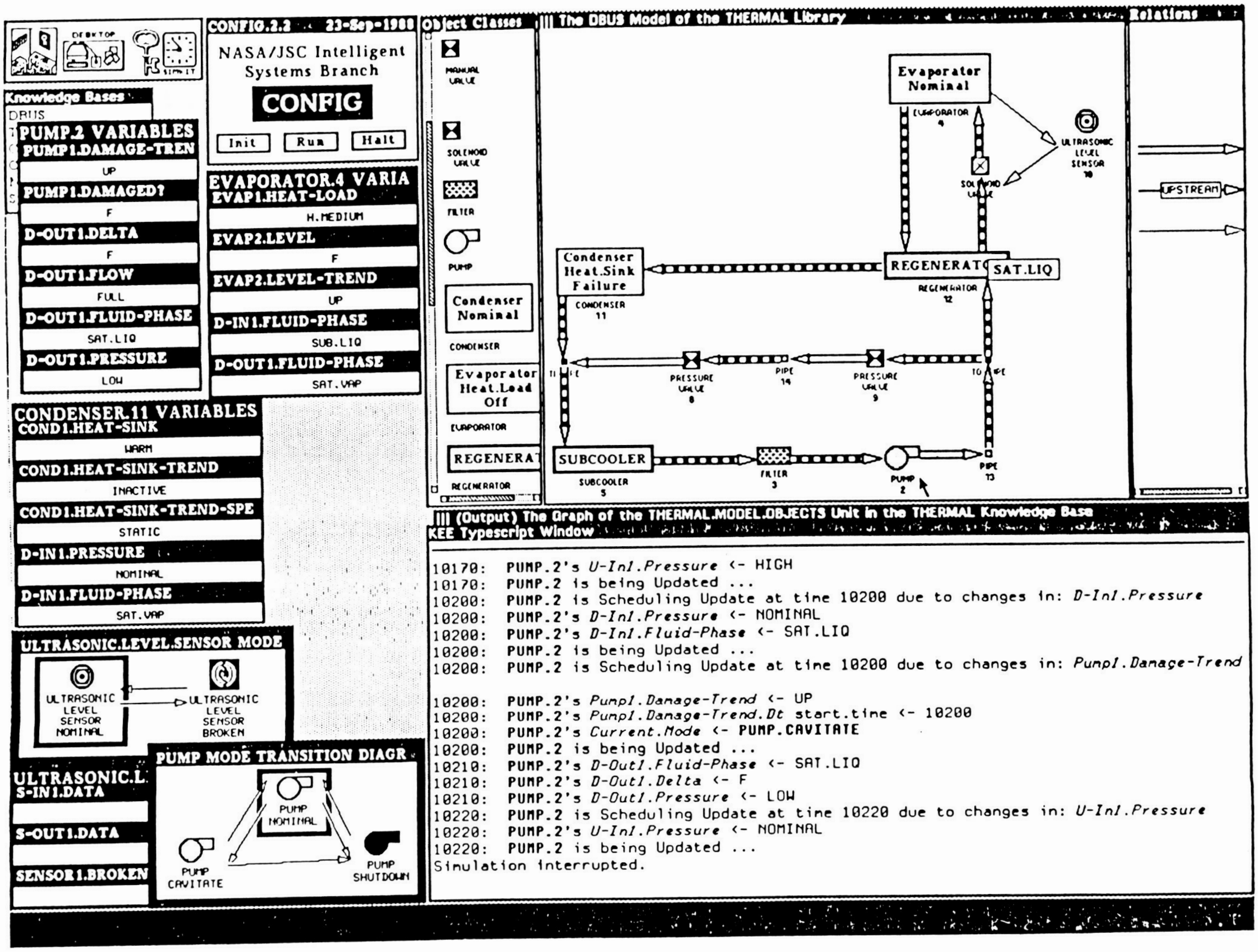
An earlier study has demonstrated that expert engineers can develop such software using simplified conceptual models of the effects of faults, failures and control actions as they propagate through a system configuration. The experts use qualitative mental simulations to trace the effects of faults through structural paths to points where these effects are detectable. These model-based analyses support development and validation of the fault management rules in the expert system.

The purpose of the CONFIG project is to incrementally develop prototypes of a generic modeling and simulation tool that provides a software version of human qualitative analyses of system behavior. The tool should support qualitative system modeling and simulation early in design, document system understanding in executable form, and support analysis of faults and failures in components and their effects on a system. The tool should support design analyses, development of intelligent fault management software and on-line intelligent fault management. It could also support operations analysis and training. CONFIG is intended to support rapid informal analysis early in system design, and modeling at a level appropriate to understanding component failures and their effects on a system. It is designed to support easy, interactive, flexible, and modular modeling and simulation of many types of space systems and their components. Test cases include a two-phase thermal bus system and a computer network.

The approach used in the CONFIG project has been to extend and combine the capabilities of both qualitative modeling and discrete event simulation. These efforts include qualitative fault modeling, and adapting discrete event structures to accommodate qualitative models of continuous processing systems.

The plans for incremental prototyping include an initial qualitative modeling and simulation prototype, CONFIG Version 2.2, which was completed in FY88. Digital circuitry and a thermal bus model were used as test cases for development and demonstration of the prototype. A draft Tutorial manual was completed for Version 2.2. A software patent application was submitted, and a paper on CONFIG was presented at the Workshop on Artificial Intelligence in Process Engineering, at the 7th National Conference on Artificial Intelligence in August, 1988.

Plans for the next year include completion of CONFIG Version 3, for partially automating and assisting model-based development and validation of fault management systems. Plans for the next year also include a Space Shuttle Engineering application of Version 2, and support of Advanced Automation studies and demonstrations. Later in the project, Version 4 will be designed to support model-based augmentation of rules and procedures for real-time management of unanticipated failures.




CONFIG Version 2.2 display.

ORIGINAL PAGE IS
OF POOR QUALITY

## Human Interface with Intelligent Fault Management Systems

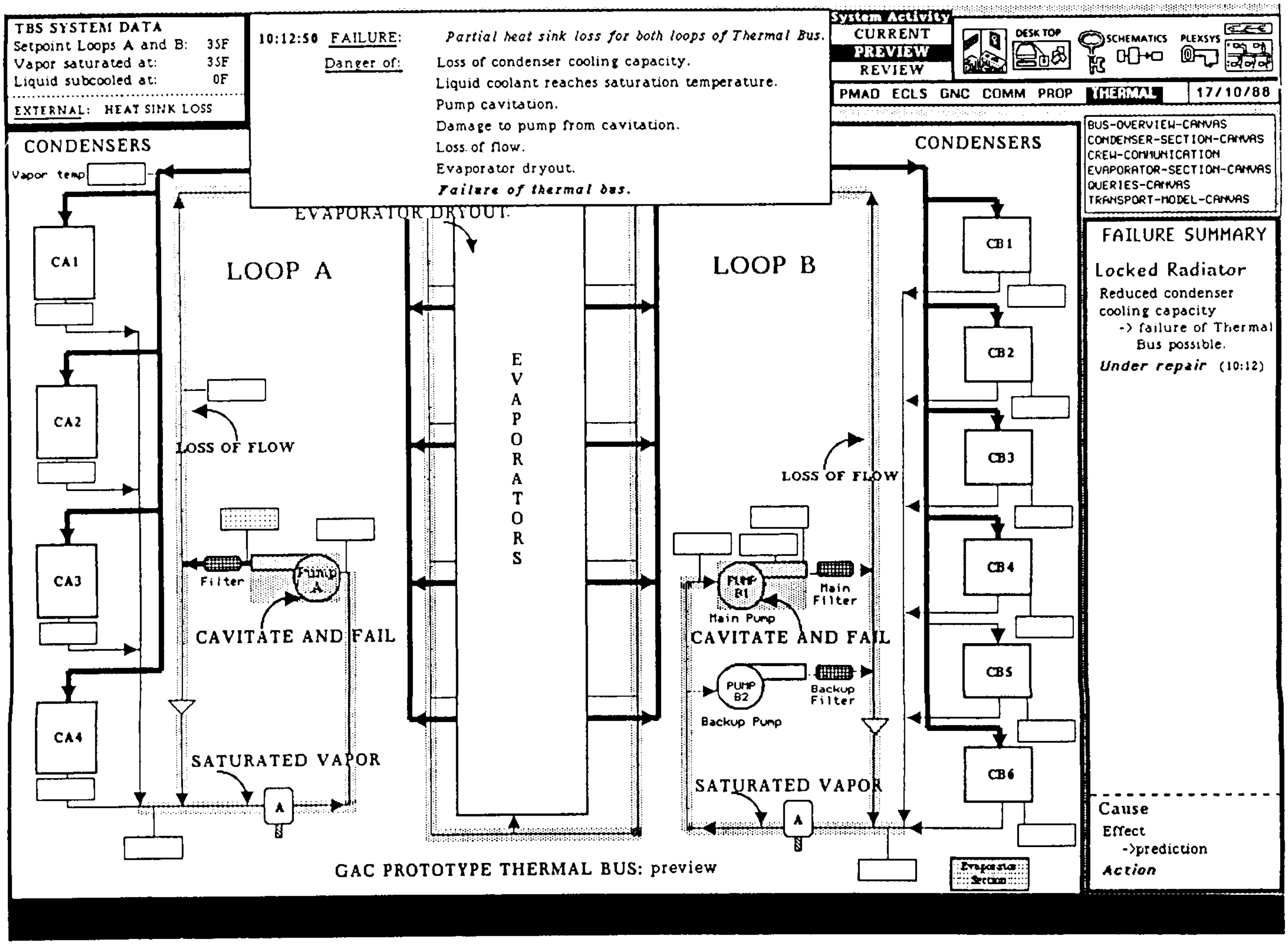
**PI: Jane T. Malin/EF5**
**Reference SST 33**

A critical technology area for future man-machine aerospace systems is artificial intelligence and expert systems. Human operators will use both rule-based and model-based software for monitoring, diagnosis and management of degraded performance, faults and failures in aerospace systems. Effective user interfaces are critical to the success of these intelligent systems, especially when the system to be managed is a complex space system. System schematics and related graphics and diagrams are commonly used by space operations personnel performing fault management tasks. User interfaces to support shared fault management by operators and intelligent systems should be based on a shared model of the system structure and function, and should be designed to make effective use of graphics to display system information. A multi-disciplinary team representing universities, industry and Government is contributing to better understanding of the use of such schematics and diagrams in the interface between a human and a model-based intelligent system. A major goal of the project is to develop a prototype software tool for designing such user interfaces based on schematic diagrams of engineered systems.

Studies have been completed on the effects of alternative diagram formats on human performance in diagnosing malfunctions in engineered systems, including a prototype Space Station Freedom subsystem. The study results indicate that interpretation of complex malfunction data is aided by showing the relevant information about states of system components at corresponding points on a schematic diagram of the system structure. A cognitive theory of diagram comprehension has been developed for tasks in managing engineered systems, and guidelines for diagrammatic displays of engineered systems have been formulated. A technical report summarizing this work has been completed.

Qualitative modeling technology is being developed to study faults and generate explanations for large-scale engineered systems. An article has been published on the role of qualitative models in several phases of intelligent computer-aided engineering and operation. Papers have been presented on an approach for managing large-scale qualitative models and on an approach for using both qualitative and quantitative representation to reason about thermodynamic cycles. The work will culminate in building prototype qualitative models of elements of a Space Station thermal control system, and demonstrating use of the models to observe faults and generate explanations.

The project will produce a software tool for constructing user-interface systems that use diagrammatic displays to support communication with model-based intelligent fault management software. A space operations fault management scenario has been developed, using a Space Station thermal control system. Using this scenario, software has been developed to demonstrate use of diagrammatic displays to aid human-machine task sharing in fault management. In the next phase of the project, the software tool for constructing the interfaces will be developed and integrated into a test bed or laboratory where design of such interfaces would take place.




Schematic diagrams can improve the human interface with intelligent fault management systems.

ORIGINAL PAGE IS
OF POOR QUALITY

## Research at the JSC/UHCL Software Engineering Research Center (SERC)

**PI:** S. A. Gorman/FR3
Dr. C.W.McKay/UHCLHighTech Lab
**Reference SST 34**

In 1983 NASA/JSC formed a research partnership with the High Technology Laboratory of the University of Houston at Clear Lake to study the software engineering issues associated with the Defense Department's Ada language initiative. This RTOP was very successful in forming cooperative links with industry and other academic institutions. The Space Station Freedom program's choice of the Ada language was heavily influenced by this RTOP's activities. This research partnership has evolved from an emphasis on Ada issues to the broader scope of software engineering and has resulted in the formation of the Software Engineering Research Center (SERC) at UHCL. The SERC seeks to establish a position of research leadership in the three environments critical to embedded system software development and maintenance: 1) the host or development environment, 2) the integration (test and verification) environment, and 3) the target environment where the application software actually executes. The SERC will also enable NASA to establish a research presence in other areas of software engineering such as innovative uses of expert systems, user interfaces, and life cycle documentation management.

JSC Software Engineering research emphasizes study of the problems related to embedded computer software development and maintenance. These are the computers which are part of a larger system (such as the Orbiter) and typically run in real-time (i.e., provide their results as they are needed; an example is the solution of the entry guidance and navigation equations during Orbiter re-entry). The research has a dual emphasis on progress in both the theoretical and technological (implementation) areas. Theoretical works usually emphasize the development of detailed conceptual models of the processes required for effective development and maintenance of software for embedded computer systems. Technological progress emphasizes actual system prototypes which provide realistic demonstrations and tests of a model's concepts.

During FY88 there were significant refinements and improvements in the Clear Lake Conceptual Model for the Software Life Cycle Support Environment. This addresses the overall life cycle processes associated with developing and maintaining embedded computer software, using the three environments noted above. This model was cited as the initial baseline for Boeing's $75M STARS contract to develop a Life Cycle Support Environment for the Joint Services.

The SERC was influential in the establishment by NASA, AJPO (Ada Joint Program Office), and DOC (Department of Commerce) of AdaNET, a life cycle oriented repository for Ada-based, reusable products and processes. Software reuse is seen as a major area for improvement of software productivity.

The SERC developed the Clear Lake Conceptual Model for Distributing Entities of Ada programs which led to the Conceptual Model for Run Time Environment Support of Mission and Safety Critical (MASC) Components. This has led to a number of invited tutorial presentations for NASA, FAA, and for IEEE, ACM, and NSIA meetings. Technological research in this area has led to prototypes demonstrating coarse grain distributions of Ada entities on existing Ada run-time environments and operating systems.

The SERC has provided further theoretical contributions in the areas of standardized operating system interface sets (such as POSIX, a standard operating system interface definition based on UNIX), Ada run-time environment services, and the integration of expert systems with more traditional software components.

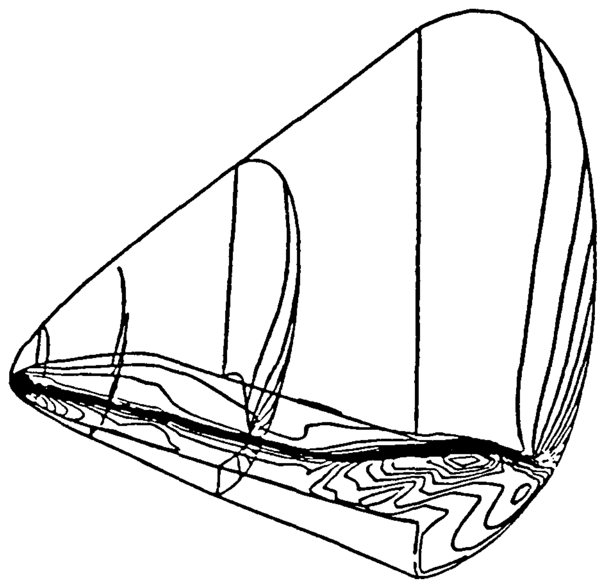
Improvements in NASA's ability to produce, maintain, and manage software are critical to the Agency's future success. The importance and expense of software becomes increasingly apparent. The special problems associated with embedded computer systems are doubly important to JSC where NASA's most significant projects of this type (Orbiter and Space Station) are centered. Current estimates of on-board code for the Space Station are approximately 30 times greater than for the Orbiter. If productivity is not dramatically improved, it will be impossible to achieve these levels within NASA's projected budgets.

## CFD Simulation of Shuttle Orbiter Entry Flow

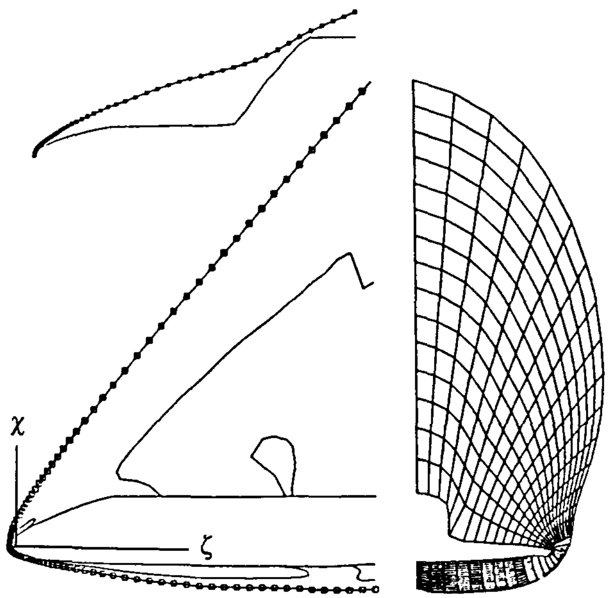
**PI: Chien-Peng Li/ED3**
**Reference SST 35**

Significant obstacles encountered in the 1970's numerical flow simulation imposed a large uncertainty band on the thermal protection system design and underestimated viscous and dissociating-air effects on aerodynamics. The preflight database was created primarily by wind tunnel testing, and partially by inviscid/boundary layer analyses assuming equilibrium air composition. Because of lack of confidence in the data for high angles of attack at high altitudes, the Orbiter cannot safely fly off-design entry trajectories. The objective of developing hypersonic technologies at JSC is twofold: 1) to support the Space Shuttle program in assessing aerodynamic loads and heating before and after flights, and 2) to validate computational fluid dynamics (CFD) codes and to understand entry flow phenomena with the aid of the flight data collected in STS 1 through 5. This effort has emphasized the application to lifting flight vehicles in continuum-flow regimes wherein finite-rate dissociations predominate. The solution technique is capable of handling both axial subsonic pockets imbedded in the shock layer and strong inviscid-viscous interactions near the wing leading edge. It is hoped that major shortcomings in current operational codes will be eliminated.

Preliminary results for a perfect-gas, finite-rate and chemical equilibrium air composition have been compared with wind tunnel data on the Orbiter and with each other. The Mach 8 pressure distribution along the body axis agrees very well with data; the chemistry effects on the body pressures are found to be consistent with the Orbiter pitching-up observed during the STS-1 flight. Shock locations are plotted in three projected views below. Distribution of grid points on the last plane is shown along with the cross section contour.



**Pressure on the surface and cross flow planes.**




**Shock shapes.**

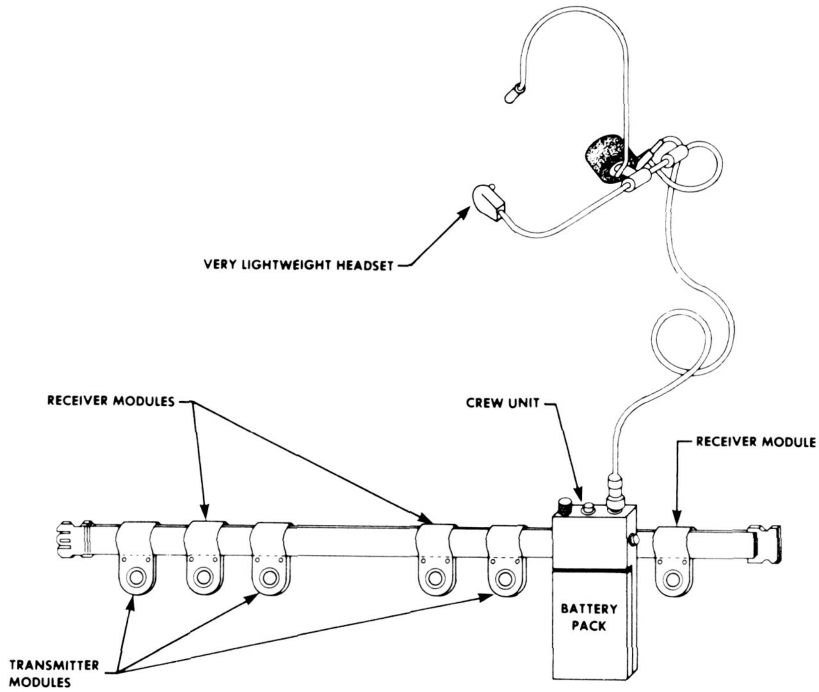
## Infrared (IR) Communications Flight Demonstration

**PI: J. L. Prather/EE6**
**Reference SST 36**

A proof-of-concept and evaluation experiment of an IR crew communications system successfully flew on Space Transportation System 26 (STS-26) in September 1988. The IR communications system was developed in order to provide better coverage and voice transmission than was available with the interim radio frequency (RF) system used previously on the Orbiter and to provide secure communications without requiring an encryption device on the crew-worn units.

Lower frequency RF systems can exhibit fading due to multipath interference within a conductive enclosure, such as a spacecraft. Infrared systems are virtually free of this phenomenon because of the extremely short wavelength (less than 1 μ). Susceptibility to electromagnetic interference, which can occur with RF systems, is also reduced. Secure onboard communications can be achieved by selecting IR wavelengths that will not pass through the spacecraft windows.

The IR crew communications system was provided as a mid-deck payload. The JSC task manager developed all the requirements and specifications; procured and modified off-the-shelf hardware; generated and coordinated all documentation, test plans, and procedures; arranged and chaired the necessary design and program reviews; and coordinated all acceptance and qualification testing. The project provided valuable hands-on experience with flight hardware, from conception to operational demonstration.




IR communications system in use on STS-26.

IR communications crew unit.

ORIGINAL PAGE IS
OF POOR QUALITY

## Optical Communication Through the Space Shuttle Window (OCTW)

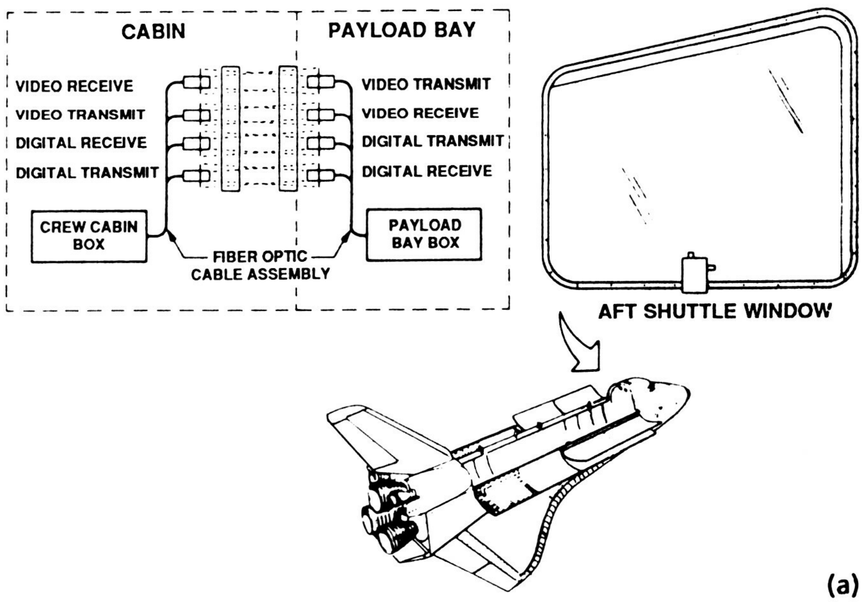
**PI: J. L. Grady/EE6**
**Reference SST 37**

In January of 1987, NASA Headquarters' Advanced Programs Office (Code M) funded a 3-year program to design and develop an alternative communication link between the crew cabin and the payload bay on the Orbiter. This alternate system will allow payload specialists to communicate with their particular payload independently of the Orbiter system and will also increase the potential bandwidth for communicating between the crew cabin and the payload bay. Fiber optics will be utilized in this system to achieve these goals. Optical fibers, transmission mediums for light, will *guide light* that is modulated with the appropriate electrical test signals to the cabin side of the aft window. There, the light (with the information stored in its intensity levels) will shine through the window and be received on the payload bay side of the window by a fiber that will guide the light to a box in the payload bay that will act as a repeater station for the test signals. Upon leaving the payload bay box the light will return to the crew cabin box again via fiber optic cable and the aft window. This box will evaluate the integrity of the optical link. Two subsystems will be a part of the OCTW system: a 200-mbps emitter coupled logic (ECL) digital link and a video link.

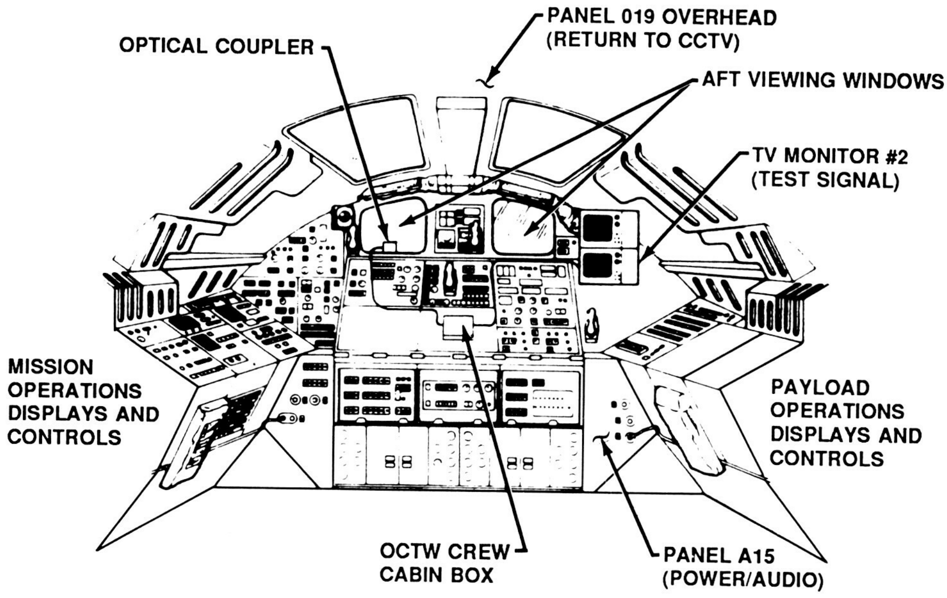
Project accomplishments in this year have included the following:

- A breadboard was demonstrated in May 1988.
- The Experiment Requirements Document was signed in June 1988.
- The Preliminary Design Review was held in June 1988.
- The following technical reports were published:
  - *Analysis of Misalignment Effects on Optical Loss Through the Window for Optical Communication Through the Shuttle Window Flight Experiment. JSC-22994, April 1988.*
  - *Optical Communication Through the Shuttle Window Laser Safety Report. JSC-22797, May 1988.*
  - *Optical Loss as a Function of Misalignment of Graded Index (GRIN) Lens for Optical Communication Through the Shuttle Window. LEMSCO-24672, December 1987.*

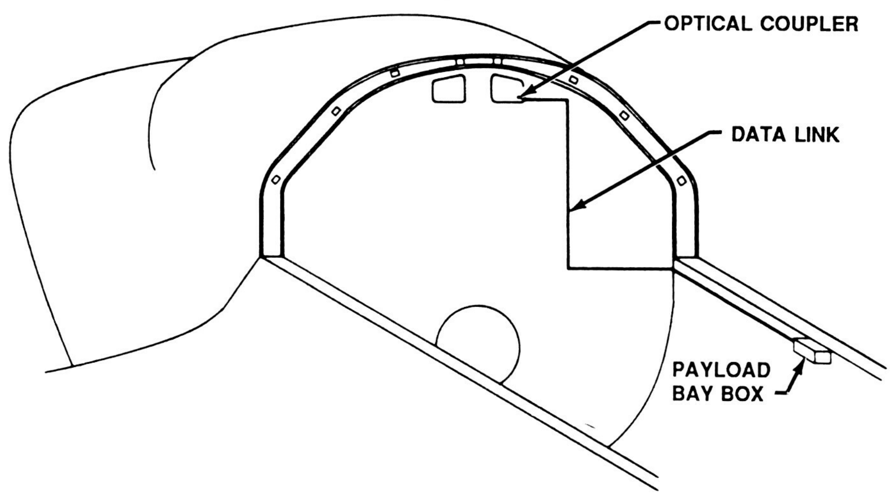
This project is consistent with the JSC's Strategic Game Plan goal of preparing now for the future. (Goal 3). The flight experiment will demonstrate the use of the ever-expanding new technology of fiber optics in the space environment (objective D and E).




(a)




(b)




(c)

**Optical communication through the Space Shuttle window.**

## Space Station Fluid Quantity Gaging

**PI: Kenneth R. Kroll/EP4**
**Reference SST 39**

Fluid quantity gaging technology is a key area in the Johnson Space Center's effort to develop an on-orbit fluid resupply capability. The Space Station Freedom and other systems performing on-orbit fluid resupply will require a fluid quantity gage to ensure that adequate fluid is available to perform operations and that excessive fluid is not delivered, wasting lift capability. This effort has the objective of identifying, developing, and demonstrating a fluid quantity gaging concept for a variety of fluids.

Current methods of gaging fluids are either sensitive to fluid position, which can not be controlled in space, or accumulated error. With current space systems, the fluid is loaded on the ground to provide an accurate initial quantity. Error accumulation with a single fluid load is not excessive for providing an adequate quantity determination. However, future space systems will require fluid resupply in space, which will allow extensive error accumulation from the ground-loaded quantity.

The compressibility method was selected after a review of all possible concepts. This method measures the pressure change from a cyclic volume change to determine the gas volume. The pressure change is directly related to the gas volume. The liquid mass is then the total tank volume minus the gas volume times the liquid density. The frequency of the volume change is set as high as possible to minimize heat transfer effects.

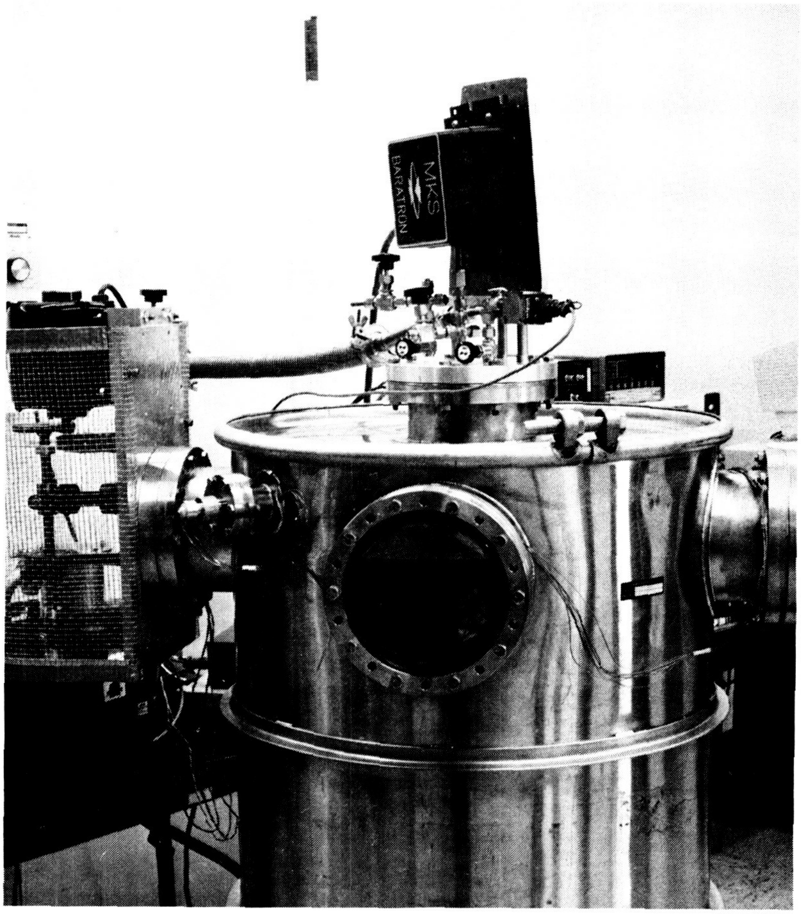
The compressibility gaging method was the only concept which was both insensitive to liquid orientation and subject to analysis. This analysis showed that a total pressure sensor can be accurate enough with electronic filtering to keep the volume change, and therefore, compressive driver mass small. In addition, all error sources can be accommodated in calculations for increased accuracy using modern microprocessors.

Proof of concept testing was conducted in a 55 gallon tank. The test setup is shown in the accompanying photo. Tests were conducted with various fluid orientations, fill levels, number of bubbles, and pressurant gases. In addition, one test series was run with thermal stratification. Accuracy was well within 1 percent.

Testing revealed that resonance must be considered when there are multiple bubbles in a tank, a condition that can be produced by a variety of causes. The resonance frequencies were evaluated for a variety of conditions. By operating with the volume change frequency at a value below the lowest resonance frequency, resonance can be avoided. This frequency would be between 0.1 and 1.0 hertz. Measuring at two frequencies allows the effects of heat transfer to be minimized at lower frequencies.

Liquid inertia in the sensing line between the tank and the pressure sensor was found to affect accuracy. The pressure sensor should be designed so that the sensing diaphragm is flush with the tank wall.

The conclusion of this activity is that the compressibility method is feasible and a practical fluid quantity gage can be developed. The pressure sensor should be able to operate with room temperature and cryogenic fluids. The computational requirements are well within simple microprocessor range. The electronics box will be small enough to work for a variety of tank sizes, while the volume change driver will have to be varied for tank size. The main design challenge will be to minimize the weight of this driver.




Compressibility gaging test facility.

**ORIGINAL PAGE IS OF POOR QUALITY**

## Aeroassist Flight Experiment Flow Simulation Development

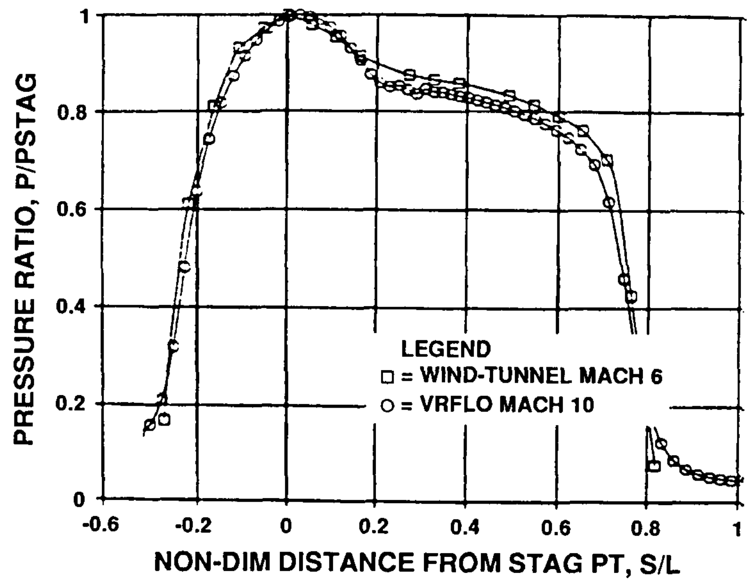
**PI: Chien-Peng Li/ED3**
**Reference SST 38**

The flow-field around an aero-braking space flight vehicle in the hypersonic reentry into Earth's atmosphere has complex dynamic behavior and physiochemical processes. The air compressed by the bow-shock undergoes dissociation, ionization and produces disparities in the internal modes of the molecules. The energy transferred to the surface creates enough heat to damage the vehicle if not properly protected. As the flow expands over the blunt face and enters the base region, the resulting shear layer coalesces and segregates the recirculation from the outer flow. Interactions between the shear layer and the vehicle can lead to serious heating of the base structure and may affect aerodynamics.

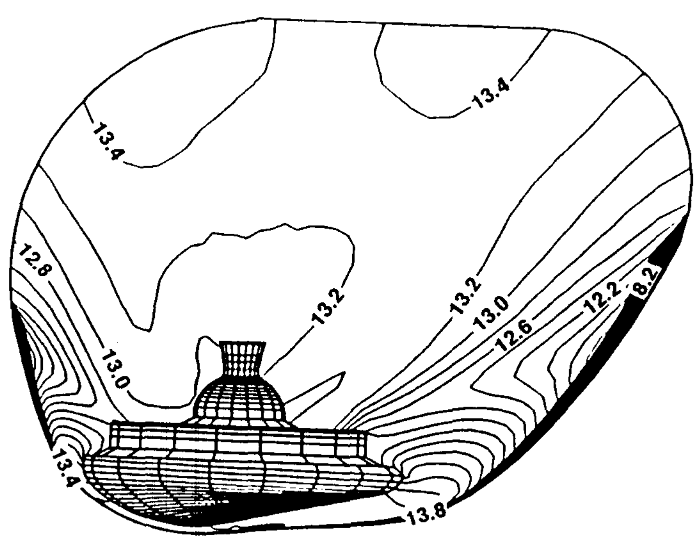
In view of the Aeroassist Flight Experiment's (AFE) design requirements and the dependence of its flight performance on the knowledge of the flow characteristics, ground-based tests have been performed to verify the proposed concept. Numerical methods have been used to simulate the wind tunnel as well as the low-density, high enthalpy flight environment. The objective was to validate the predictions at wind tunnel conditions and to provide data as precise as possible for the design of a flight experiment vehicle and its onboard instruments. The data acquired in the experiment will then fill a void in the hypersonic data base which can be used, in turn, to validate the prediction methods at flight conditions.

A comparison of the Mach 6 pressure data taken from wind tunnel tests is made with the Mach 10 predictions by the Vibrous Reacting Flow (VRF) program. A small discrepancy in the stagnation pressure causes the distribution to shift downward slightly, but the similarity in shape is encouraging.

To support the design of onboard lee side flow experiments, the flight environment was simulated in which air reacts at finite rate and flow near the AFE vehicle has viscous behavior. It was found that a fairly high concentration of electrons exists in the entire base flow.




Comparison of prediction predictions with wind tunnel measurements in the pitch plane.




Contour plots in the pitch plane of the number density of electrons.

## Catalytic Surface Effects Experiment

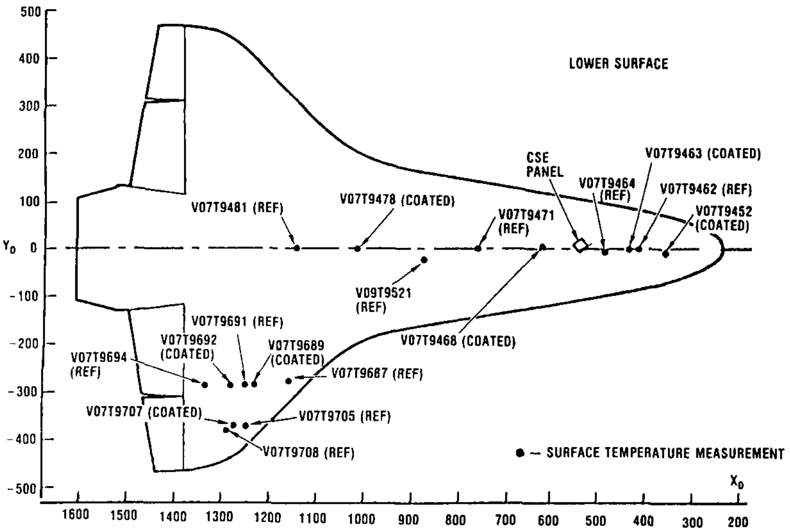
**TM: R. Richard/ID3**
**PI: D. Stewart(ARC)**
**Reference SST 40**

*A major portion of the thermal* protection system (TPS) on the underside of the Space Shuttle consists of radiatively cooled lightweight tiles which are made rigid with fibrous ceramic, coated with cured glass (RCG). The material used in fabricating these tiles is called high-temperature *reusable surface insulation* (HRSI). During atmospheric entry, dissociated oxygen tends to recombine near the tile surfaces, releasing heat and increasing the temperature. If the tile surfaces are catalytic, the recombination reaction goes to completion, causing an even higher temperature.

*Reducing entry heating by using* noncatalytic surfaces is an attractive possibility. Verification of this phenomenon with wind tunnel data has been unconvincing because of uncertainties about the composition and contamination of the arc-heated air streams. In spite of the uncertainties, initial estimates of catalycity used in the Space Shuttle TPS design and in the experiment design were necessarily based on procedures developed and tested using data from arc-heated wind tunnels. The uncertainties led TPS designers to be overly conservative and assume full catalycity. The situation has now changed, however, in that the advent of the Space Shuttle Orbiter Experiment (OEX) Program has made it possible to determine the actual catalytic efficiency of the TPS under flight conditions.

The Catalytic Surface Effects (CSE) experiment utilizes baseline flight tiles and an onboard instrumentation system, also part of OEX, to measure the catalytic efficiency of the Space Shuttle TPS without affecting flight operations. *A highly catalytic overcoat is* sprayed onto selected titles (seven), and these, as well as adjacent uncoated titles, are instrumented to measure temperature. The second flight of the CSE experiment will usea variant configuration of the Tile Gap Heating Experiment panel, in which a number of tiles were *mounted on an aluminum carrier* plate to facilitate instrumentation and ease of removal and reinstallation.

The CSE experiment was designed to demonstrate conclusively whether the Space Shuttle TPS tiles are catalytic or non-catalytic to the recombination of dissociated air Omolecules. There have been four flights of the CSE experiment on Orbiter OV-102 (Columbia). These flights have shown that the tiles are indeed non-catalytic, and the result is a reduction of from 70 degrees (K) to 200 degrees (K) from equilibrium. Future flights will improve the present estimates, and will better map the spatial extent of the non-catalytic heating reduction. There are regions of the Space Shuttle such as the elevons, body flaps, and wing leading edge, which are particularly difficult to analyze, and greater reliance will have to be placed on a flight-test program. The importance of knowing the catalytic efficiency lies in the fact that if the efficiency is lower, the flight envelope and life of the Space Shuttle would be extended. Also, this information would be important to future advanced designs.




**Surface temperature measurements from catalytic surface effects experiment.**

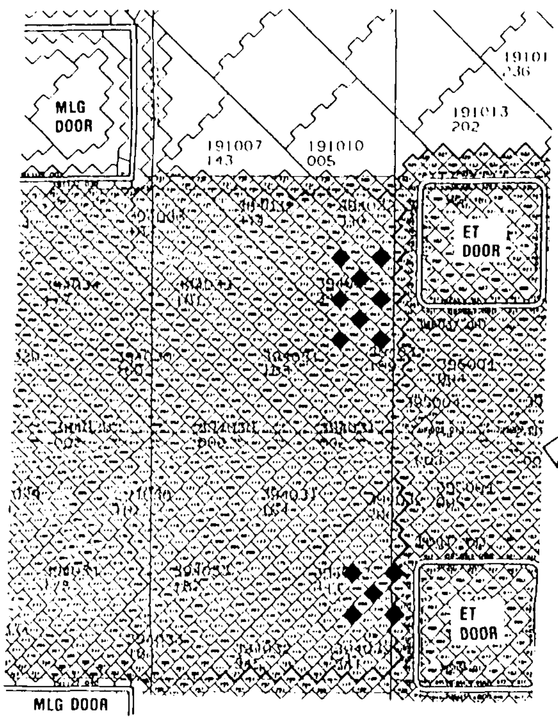
## Toughened Uni-Piece Fibrous Insulation (TUFI)

**TM: R. Richard/ID3**
**PI: D. Leiser (ARC)**
**Reference SST 41**

Thermal protection for the underside of the Space Shuttle is accomplished primarily by lightweight tiles composed of a rigid, fibrous ceramic material designated HRSI (High-temperature Reusable Surface Insulation). This material, coated with reaction cured glass (RCG), is subject to damage from the many sources associated with Space Shuttle operations. These sources include ice particles, insulation particles (from the outer covering of the External Tank), and dirt or gravel from the landing site. Tiles subjected to this damage must be replaced prior to each flight at considerable expense. The possibility of developing a tile which might be less susceptible to the kind of damage alluded to was the impetus for the TUFI experiment, made possible by the Orbiter Experiments (OEX) Program.

The basic TUFI material is AETB-12 (Alumina Enhanced Thermal Barrier). Whereas the baseline HRSI (also designated LI2200) is composed of silica fibers with about 10 percent silicon carbide, AETB-12 is composed of 12 percent Nextel (a 3M Trademark for aluminoborosilicate), 20 percent alumina fibers, and 68 percent silica fibers. The AETB-12 has a better temperature capability than the HRSI --2900 degrees F versus 2700 degrees F. One other significant departure in comparisons of the baseline tile and the TUFI is in the coatings. The HRSI coating is one coat of reaction cured glass (RCG); the TUFI is a special coating developed by Ames Research Center. Four coats of this coating are applied, air dried after each application, then sintered.

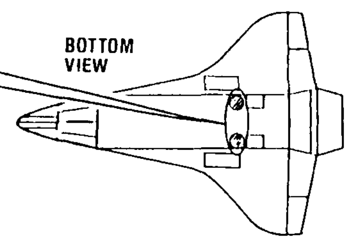
Thirteen tiles are used in the TUFI experiment at locations selected based on studies which showed the areas most subject to particulate damage. Five tiles are forward of the right External Tank (ET) door, and eight are forward of the left ET door. The instrumentation consists of four temperature measurements. Objectives of the experiment are to evaluate TUFI tiles under worst case environmental conditions and to compare the performance with baseline HRSI tiles.



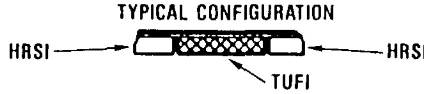

IMPLEMENTATION:
REPLACE 1 EA TILE WITH TUFI TILES AS FOLLOWS

| RIGHT SIDE, 5 TILES | | LEFT SIDE, 8 TILES | |
|---|---|---|---|
| V070-394032 | -089 | V070-394031 | -044* |
| | -091 | V070-394032 | -055 |
| | -106 | | -057 |
| | -210 | | -071 |
| | -313 | | -073* |
| | | | -075 |
| | | | -224 |
| | | | -365 |

NOTE*: INSTRUMENTED TILES WITH 1 SURFACE THERMOCOUPLE & 1 RSI / SIP THERMOCOUPLE




TYPICAL CONFIGURATION




Advanced rigid insulations.

ORIGINAL PAGE IS
OF POOR QUALITY

## Base Flow and Heating Experiment

**PI: Carl D. Scott/ED3 and Michael C. Jansen/ED3**
**Reference SST 42**

The design of aeroassisted vehicles and the protection of the payloads on the lee side of these high-velocity, blunt vehicles require an understanding of the complex flow phenomena in the base region. This flow, at high altitudes and high velocity, is in chemical nonequilibrium and is partially ionized. The gas may radiate as well as convect heat to the afterbody; and, the high energy flow may impinge on it, if the afterbody extends into the high speed flow beyond the recirculating base flow. Moreover, base and wake flows typically are unsteady and perhaps contain vortices shed from the vehicle.

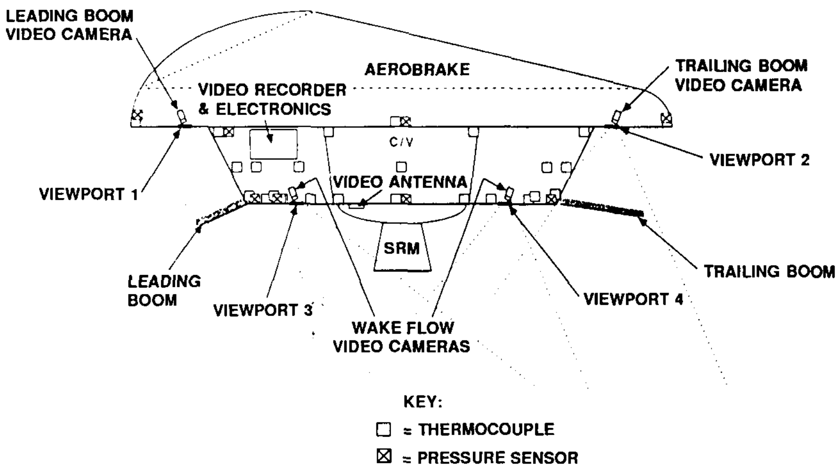
Gaining an understanding of this complex flow-field is one of the principle aims of the Aeroassist Flight Experiment (AFE), to be launched and recovered by the Space Shuttle in 1994. This research vehicle will have onboard a set of experiments called the Base Flow and Heating Experiment (BFHE). Its objective is to obtain information needed to verify design methodology and to understand the high temperature chemistry and dynamics of blunt vehicle wakes and base flow-fields.

There are basically four sets of instruments being planned for measuring surface and flow-field properties during the atmospheric flight of the AFE vehicle. These are heat flux and pressure measurements, electron and ion concentrations, and a set of four video cameras. Base surface heating and pressures will be measured on the lee side of the vehicle itself. There will be instruments located on booms extending into the base flow to measure properties of the flow away from the surface of the vehicle. These booms will be covered with high-temperature Space Shuttle tile insulation. In addition, pictures of the radiating wake and base flow, and its impingement on the booms, will be recorded with a set of four video cameras mounted just inside the vehicle and looking aft.

The pressure and heat flux measurements on the surface of the vehicle will be compared with computational fluid dynamic predictions to validate the methods. These validated methods will be used to help design the aerobraking vehicles envisioned for use as transportation to and from geosynchronous orbit, the Moon, and even Mars. Techniques to measure the heat fluxes on the flexible fibrous external insulation to be used on the lee side of the AFE are being developed; these techniques will be tested soon in arc jet facilities which simulate high temperature reentry flow. Measuring the very low pressures in the base of the vehicle presents a significant instrumentation challenge. Light weight, very low range pressure transducers are being investigated for application on the AFE. The flow impingement pressure readings from several locations on the booms will help in understanding the properties of the base flow. Likewise, thermocouple measurements of the boom surface temperature distribution will determine the heat flux which will complement the pressure information in characterizing the impinging flow. Langmuir (electrostatic) probes mounted on the booms will measure electron and ion current from which electron and ion densities, electron temperature and flow velocities may be obtained. Two of the cameras will be focused on the booms to obtain information about the radiating gas around the booms and about the thermal radiation from the booms themselves. The other two cameras will stereoscopically view the wake closure region. From these images, the distance to closure region may be obtained, again for comparing with computations and for estimating the dimensions of the base region that is in the low-velocity recirculation zone.

This year's accomplishments include the breadboarding of the camera system and beginning of its checkout; the design of an arc jet test article for evaluation of the boom design and its tile joints and instrumentation installation; selection of a contractor for the Langmuir probe system; and preliminary design of the pressure ports.

The Base Flow and Heating Experiment will afford a unique measurement opportunity. Its cluster of measurements will be the most comprehensive set ever obtained in the base flow of a flight vehicle.




**Base flow heating experiment locator schematic (side view).**

# Solar Systems Sciences

## Summary

## Solar System Exploration

### Introduction

NASA has established three initiatives leading to the manned exploration of the solar system - the creation of a permanent manned lunar base, an unmanned Mars sample return mission, and a manned mission to Mars. Planetary science research at the Johnson Space Center supports the center's aim of developing concepts which will be used in these initiatives. In the Solar System Exploration Division, research is conducted into both the characteristics, origin and evolution of the terrestrial planets, asteroids and satellites (the rocky bodies located in the solar system), and research into the practical uses of resources found on these planets to support and maintain manned expansion into the solar system. These investigations are performed by:

- Analyses of planetary materials
- Experimental simulation of planetary conditions and processes
- Remote sensing observations
- Theoretical modeling of analytical, experimental and observational data.

These studies contribute to a scientific base of knowledge from which the mission scientific objectives and instrument design criteria can be developed. Highlights of recent planetary science research at JSC are summarized below.

### Lunar Sample Studies

The curation and study of extraterrestrial materials, including lunar samples, meteorites and cosmic dust particles is heavily emphasized in solar system research at JSC. These extraterrestrial materials are the only samples we have in-hand with which to study the origin and evolution of the solar system. The lunar samples collected as part of the Apollo program are curated at JSC and distributed to scientists at many institutions for research projects. Research at JSC on the lunar samples has contributed to our understanding of the accretion of planetesimals and differentiation processes of other planetary bodies. The recent identification of new members of mafic (igneous rocks with a low silica content) intrusive rocks found in Apollo 15 samples taken from depths below the lunar surface, and a new type of igneous rock from the lunar highlands will refine our understanding of the lunar differentiation process. These and other studies of the returned lunar samples provide a wealth of information for the design of unmanned and manned lunar missions culminating in the permanent manned lunar base. Lunar soils and rocks also provide sample materials for testing the uses of *in-situ* resources in preparation for a manned lunar base.

### Meteorite Studies

The science of meteoritics, or the study of meteorites and what can be inferred from them about the origin and history of the solar system, constitutes a major part of the research at JSC. From records of the early solar system preserved in the different types of meteorites, we have learned about the composition of the Sun and planets, the existence of ancient magnetic fields, and heating events in the solar system. During the past 13 years, scientists from the U.S. have travelled to Antarctica to collect meteorites, increasing the total number of known meteorites by a factor of 2 - 3. Meteorites are found in abundance on some of the slower-moving glaciers. These meteorites have either fallen directly onto the ice in roughly the same locations during recent Earth history, or fell on the ice further back in time, were buried into the glaciers, and have surfaced as the top layers of the glaciers have ablated. The identification of the meteorites on the ice is straightforward, and they are collected in much the same way that the astronauts collected lunar rocks during the Apollo missions. The meteorites collected in the Antarctic are shipped still frozen to Houston and are curated at JSC. These meteorites then become a large repository of extraterrestrial material available for scientific study.

At JSC, recent studies of some unusual meteorites have provided scientists with new pieces of the puzzle of solar system history. Radiologic age-dating of a group of rare meteorites called mesosiderites (basaltic regolith breccias in which the mixing of metals and silicates probably took place when the metal was molten) suggest that these rocks formed no earlier than 4 billion years ago. The thermal history data suggest a scenario in which the original mesosiderite parent asteroid was fragmented during a collision with another asteroid. The material created by the collision then gravitationally reassembled, and the mesosiderite material was buried in the interior of the newly-created asteroid. Studies at JSC of meteorite LEW 86010 collected at the Lewis Cliffs, Antarctica, in 1986 show that it probably originated as part of the same parent asteroid as another meteorite named Angra dos Reis (ADOR). Both of these meteorites are apparently among the oldest materials found in the solar system. Unlike ADOR, however, the heating record in LEW 86010 has been preserved. The sequence of events during the heating period observed in LEW 86010 should provide some clues as to early solar system conditions and the processing of natural materials.

Three radioactive age decay techniques have been investigated at JSC for possible use with age-dating iron-nickel (metallic) meteorites: palladium-silver (Pd-Ag), lead-thallium (Pb-Tl), and uranium-thorium-lead (U-Th-Pb). The decay of $^{107}$Pd to $^{107}$Ag appears to be the most promising for radiologic age-dating in iron meteorites. The nucleus $^{107}$Pd has a "short" half-life of 6.5 million years before it decays to $^{107}$Ag. The discovery of $^{107}$Ag in iron meteorites suggests that 107Pd existed at the time the meteorite was formed, and that the lead had not had enough time to decay totally, since the time it was created by an earlier process in stellar history. Other research into meteorite formation at JSC suggests that three different groups of meteorites - the eucrites, diogenites and howardites - probably formed in the

PRECEDING PAGE BLANK NOT FILMED

PAGE 68 INTENTIONALLY BLANK

same parent body, but came from different heated and melted parts of that body.

### Cosmic Dust Studies

Cosmic dust particles are considered to be very primitive solar system material, possibly the oldest extraterrestrial material we have obtained. Sources of cosmic dust are thought to include comets and asteroid debris, and interstellar matter. Comets are postulated to have formed in the distant outer parts of the solar system, where ices have trapped interstellar dust particles. A pristine comet should contain these primitive materials which may have been building blocks for the solar system, providing clues to the origin of the solar system. Scientists have a strong interest in retrieving these primitive materials in order to study the origin and evolution of the solar system. At JSC, scientists maintain a program of collection of cosmic dust, using flights of NASA aircraft equipped with special cosmic dust collectors through the Earth's stratosphere. The curation of these particles is conducted at JSC.

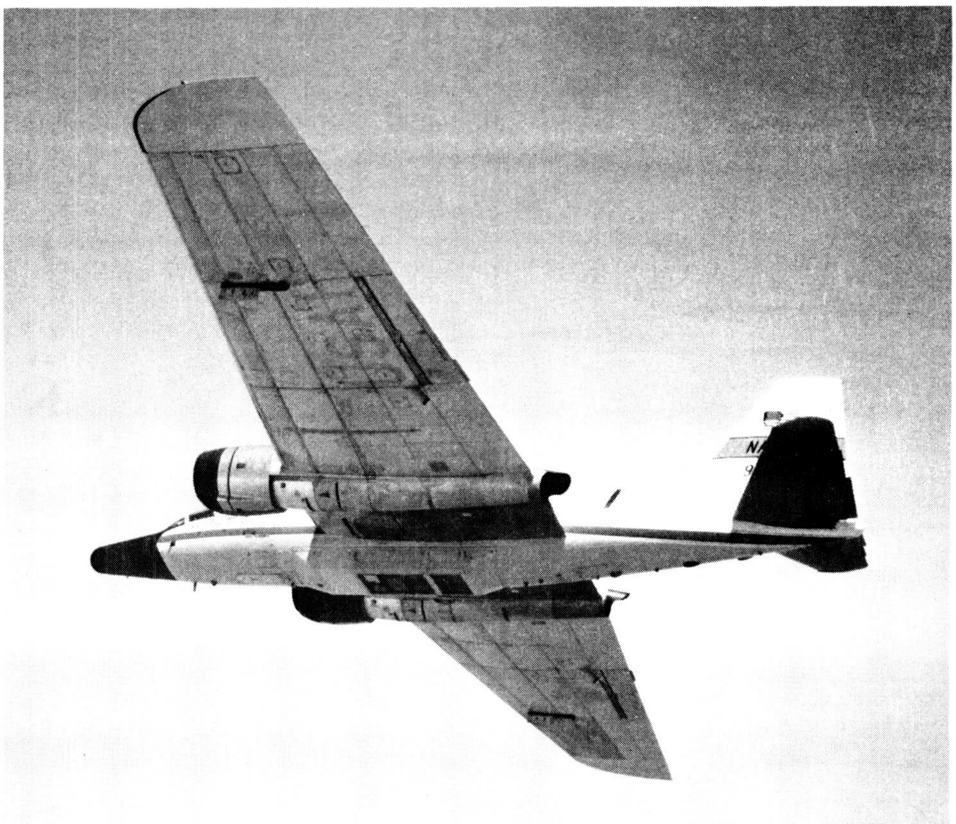
Science studies emphasize understanding the properties of these particles. Recently, an increase in the number of particles rich in materials common to manmade rocket bodies has been found among the particles trapped by the cosmic dust collectors. This increase suggests that manmade debris in low Earth orbit has increased in volume in recent years. JSC scientists have also been instrumental in the development of a proposed cosmic dust collection facility for the Space Station Freedom, thus extending cosmic dust research into the next major step of the manned space program.

### Life Support System Research

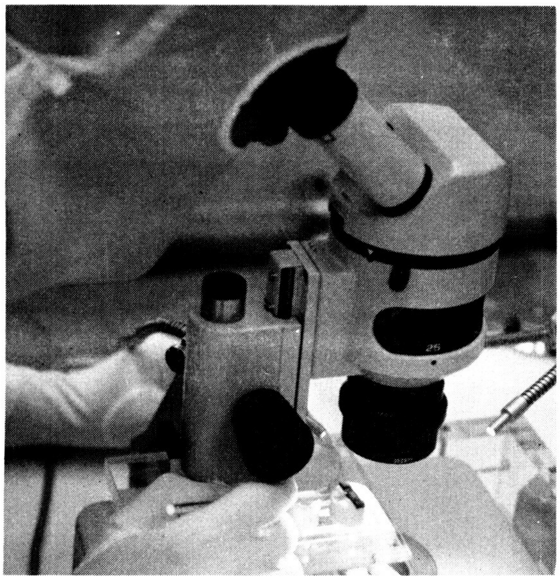
The long-term operation of Space Station Freedom and a permanent manned lunar base will require food production and the efficient disposal of human waste in both of these locations. Scientists at JSC have been actively involved in research aimed toward developing a soil derived from lunar materials which would support food growth and function as part of a recyclable life support system. A group of minerals called zeolites are very efficient at producing materials which promote the retention of nutrients for plant-supporting soil under moderate temperature and pressure conditions.

### Spectral Studies of Terrestrial Planets and Asteroids

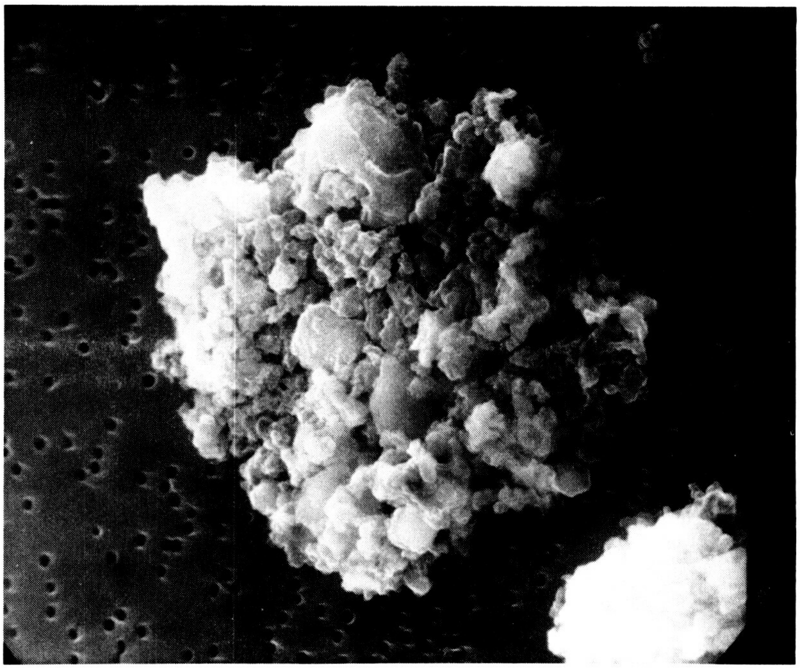
Information about the composition of the surfaces and atmospheres of planets can be acquired by remote-sensing ground-based telescopic observations made of these objects. The spectrum of reflected sunlight from a rocky planetary surface will be affected by the mineralogical composition of the upper thin layer of surface material and by the amount and composition of the atmosphere above the surface. Scientists at JSC have discovered the atmospheric components of the metals sodium and potassium in the exospheres of Mercury and the Moon. Theoretical modeling is underway to determine the mechanisms needed to create these atmospheres and any implications for the surface composition of these objects. Prior studies of the composition of the lunar surface as determined from rocks returned by the Apollo program provide scientific tie points for the sodium and potassium observed in the lunar atmosphere. Spectra have also been acquired of asteroids whose material has not been reworked by solar heating effects due to their distances from the Sun. Weak absorption features similar to features seen in laboratory spectra of meteorites found on the Earth have been identified in the spectra of some asteroids. At JSC, laboratory work has also been conducted showing that the spectral properties of hematite (an iron oxide rust) simulate spectra obtained telescopically of the Martian surface soil, suggesting that the martian surface is highly oxidized.



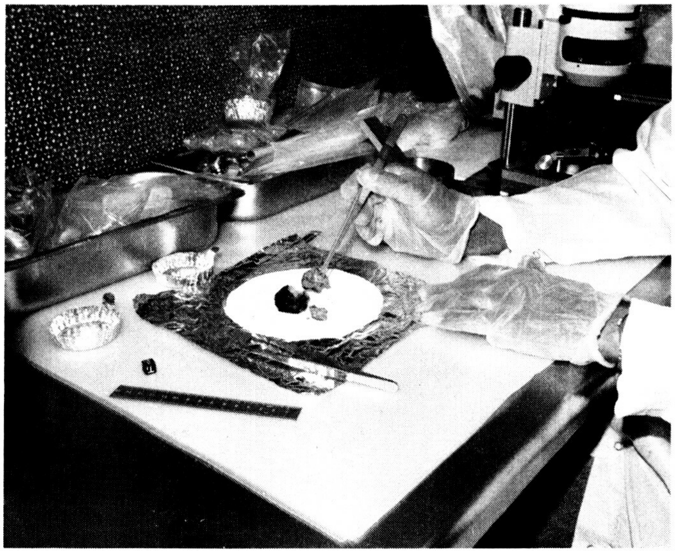
**High altitude aircraft carrying a cosmic dust collector (visible just under each wing) which traps particles in the Earth's stratosphere.**



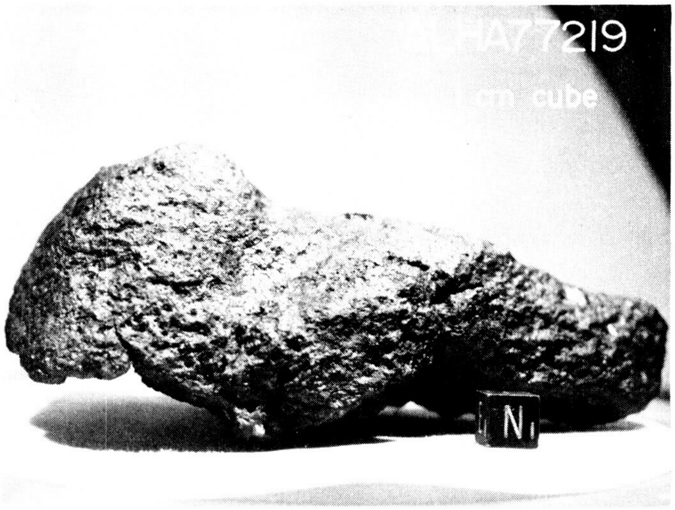
A JSC scientist examines cosmic dust particles using a binocular microscope.



Electron microscopic pictures of a cosmic dust particle collected from the stratosphere.



A JSC scientist examines a meteorite.




A sample mesosiderite found in Antarctica.

# Solar Systems Sciences

## Significant Tasks

PRECEDING PAGE BLANK NOT FILMED

PAGE 72 INTENTIONALLY BLANK

## Experimental Geochemical Studies Related to the Chronology of Iron Meteorites

**PI: John H. Jones/SN2**
**Reference SSS 1**

Iron meteorites are assemblages of iron-nickel metal, troilite (FeS), schreibersite ($FE_3P$), and other minerals in trace or minor abundances. Three major radioactive parent-daughter systems have been investigated in chronological age-dating studies of iron meteorites:

- Uranium-thorium-lead, where $^{238}U$, $^{235}U$ and $^{232}Th$ decay to $^{206}Pb$ and $^{208}Pb$, respectively;
- Palladium-silver, where $^{107}Pd$ decays to $^{107}Ag$;
- Lead-thallium, where $^{205}Pb$ decays to $^{205}Tl$.

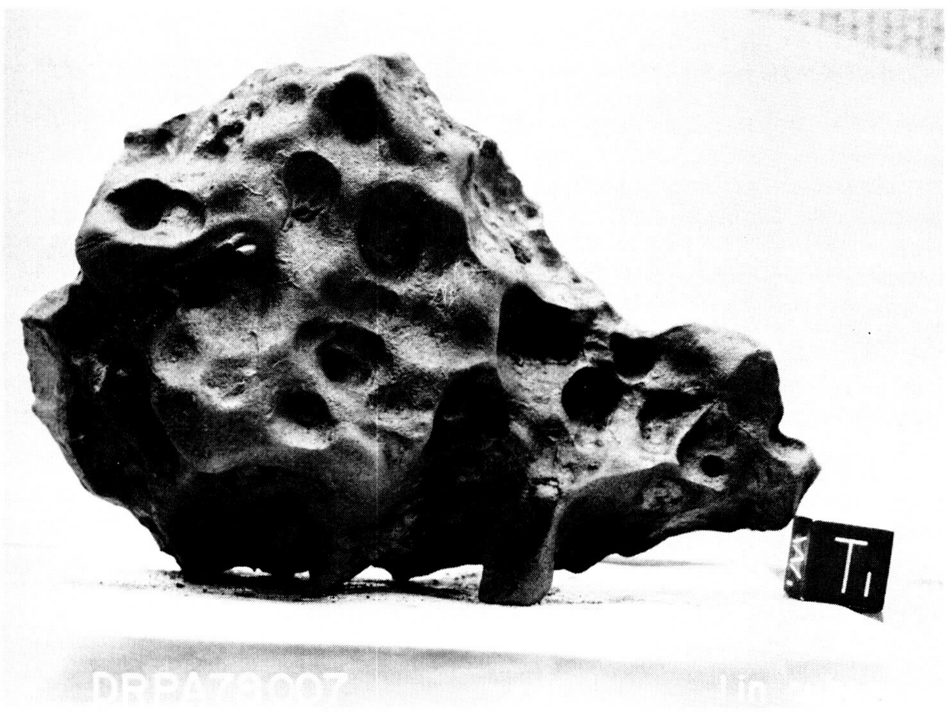
The importance of these studies is twofold. Firstly, the analysis of Pb in iron meteorites has established the initial Pb isotopic composition of the solar system and has, therefore, allowed a determination of the age of the solar system -- 4.5 billion years. Secondly, the discovery of $^{107}Ag$ and $^{205}Tl$ anomalies in iron meteorites has confirmed that the "short-lived" nuclei $^{107}Pd$ and $^{205}Pb$, whose half-lives are 6.5 million years and 14 million years, respectively, existed at the time of the formation of meteorites and planets and had not yet had time to completely decay since the time of their creation by some earlier stellar process.

The study described here is designed to improve our understanding the geochemistry of Ag, Pb, Pd and Tl in metallic (iron meteorite) systems. If the host mineral phases of these elements are known, the geochronological studies can be refined. For example, if the host phase of Pb could be separated and concentrated prior to analysis, then many analytical problems related to terrestrial contamination could perhaps be reduced. Further, there should, in principle, be a general correlation between the solubility of Ag, Pb, Pd and Tl in the mineral phases studied experimentally and the abundances of these elements measured in minerals separated from iron meteorites. Further, should the experimental and analytical studies be found to be inconsistent with each other, then some re-evaluation would be necessary.

**Pd-Ag system**. This system is nearly ideal for chronological studies because Pd and Ag are geochemically very different. Experiments have shown that Pd readily enters the metal phase while Ag is efficiently excluded. Chronological studies confirm the experimental expectation that sulfides and phosphides have low $^{107}Ag$ contents while the metal phase, that originally had nearly all the $^{107}Pd$, has relatively large quantities of $^{107}Ag$. Thus, the experiments and the analysis of iron meteorites agree.

**Pb-Tl system**. This system appears to be a difficult system for isotopic studies, because Pb and Tl are geochemically similar. Experiments show that both Pb and Tl are efficiently excluded from all the major mineral phases of iron meteorites -- metal, troilite and schreibersite. Thus, the Pb and Tl probably exist in minor or trace phases that are small and spatially associated with each other. Under these conditions, it appears to be difficult to achieve good separation of Pb and Tl and makes the search for $^{205}Tl$ anomalies more difficult. This is also seen in the analytical data on iron meteorites, where $^{205}Tl$ anomalies are difficult to find and are not reproducible from meteorite to meteorite.

**U-Th-Pb system**. As the preceding section implied, the host phase for Pb (and Tl) in iron meteorites is still unknown. In laboratory experiments where a metallic liquid is present, Pb is extremely insoluble in (Fe, Ni) metal, very insoluble in troilite and rather insoluble in schreibersite. However, it is possible that, at low temperatures where no liquid exists, Pb, having no place else to go, will prefer schreibersite. It may be fruitful to analyze schreibersite separates both for primitive Pb and for $^{205}Tl$ anomalies.




A sample iron meteorite found in Antarctica.

## A Unique Antarctic Meteorite: Possible New Clues to the Early History of the Solar System

**PI: Gordon A. McKay/SN2**
**Reference SSS 2**

A fundamental goal in planetary science is to learn more about the earliest history of the solar system. Most of our information about this period comes from detailed studies of meteorites. The meteorite Angra dos Reis (ADOR) is particularly informative regarding the nature and chronology of events in the early solar system. First, the isotopic composition of strontium in this sample indicates that ADOR was isolated from the radioactive parent element, rubidium, very early in solar system history, before that in almost all other meteorites. Moreover, ADOR has a very old crystallization age, 4.54 billion years, indicating that its isotopic and chemical characteristics have been undisturbed since very early times. Finally, the abundance of a number of key elements in ADOR are highly fractionated, indicating that its precursor material underwent extensive chemical processing, either in the solar nebula before formation of its parent body, or later, within the parent body.

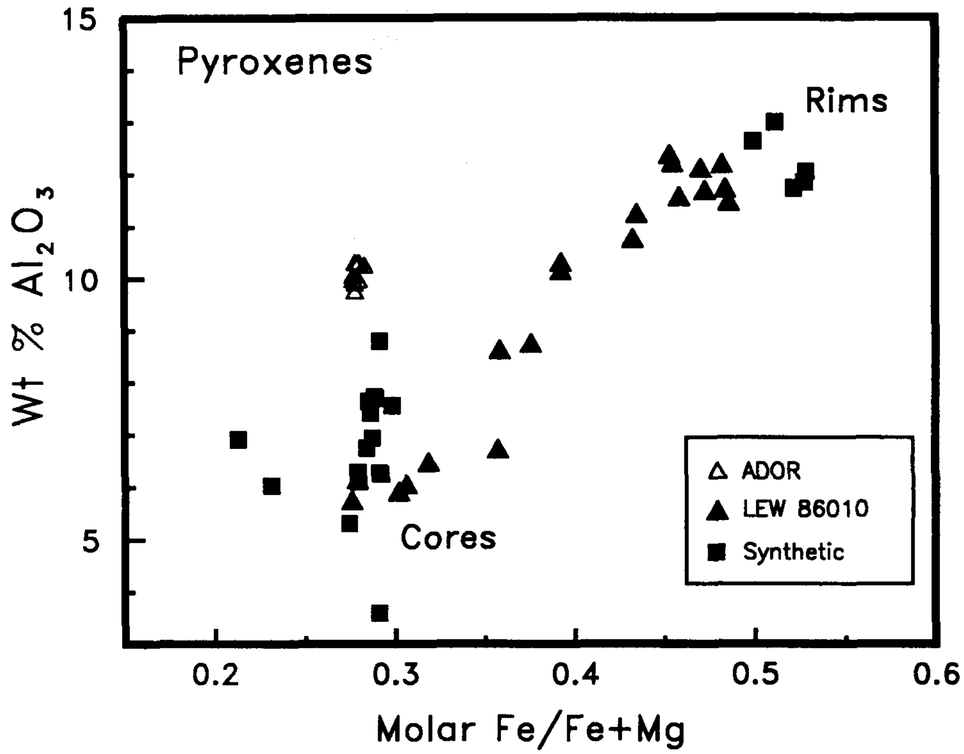
Several questions arise regarding how ADOR acquired its unusual characteristics. To what extent are those characteristics the result of nebular rather than planetary processes? Is ADOR from the same parent body as another group of old differentiated meteorites called basaltic achondrites, making differences in intensity and timing of planetary processing responsible for the differences in chemical and isotopic characteristics, or are they from separate parent bodies which acquired different chemical and isotopic characteristics as a result of nebular processes? Can the effects of planetary processes be unraveled to reveal the composition of ADOR's parent body, in order to understand the nebular processes which produced that composition?

Answering these questions has been difficult, because the nature of the planetary processes involved in ADOR's formation are not well understood. Study of additional meteorites related to ADOR might shed light on these processes. Unfortunately, until recently no other meteorites were known to be related to ADOR. Therein lies the significance of LEW 86010, a unique meteorite recently collected from Antarctica. We performed a detailed study of this sample that revealed unusual enrichments or depletions in a number of chemical elements, similar to the ones observed in ADOR. For example, in both meteorites the mineral pyroxene is unusually enriched in aluminum and titanium and depleted in sodium. Moreover, olivine, another common meteoritic mineral, is unusually enriched in calcium in both samples. Based on the observed similarities, it appears likely that these samples are from the same parent body.

These studies also revealed significant differences between LEW 86010 and ADOR, which might provide important clues to differentiation processes on their parent body. The mineral grains in ADOR are highly equilbrated, as if the sample were recrystallized by a long heating episode after initial solidification. Thus, it appears that the record of melt composition typically contained in igneous minerals has largely been erased from ADOR. Minerals in LEW 86010, on the other hand, still contain a record of melt evolution. For example, pyroxene grains show typical igneous variations in iron, magnesium, titanium, aluminum, chromium, and rare earth elements from core to rim, in contrast to the homogeneous ADOR pyroxenes. Furthermore, crystallization experiments on LEW 86010 analogs produced minerals having the same unusual compositional characteristics as those in the meteorite. Thus, evidence supporting an igneous origin for LEW 86010, with much less recrystallization than ADOR, is unequivocal.

Future crystallization experiments are planned to investigate the nature of the source region where the LEW 86010 melt may have formed. For example, with additional study it might be possible to compute the degree of chemical fractionation which such a melting episode produced, thus allowing an estimate to be made of what proportion of the observed chemical fractionation occurred on the parent body and what proportion occurred via nebular processes.

In summary, LEW 86010 is an extremely interesting meteorite of clear igneous origin, is probably closely related to ADOR, and most likely crystallized from a melt of its own composition. We have organized an international consortium of investigators to study the chronology, chemical and isotopic characteristics, cooling rate, and many other aspects of LEW 86010 in great detail. All of these studies will be performed on a tiny sample which is smaller than a marble (it weighs only 5 grams) but which contains important clues to events that occurred during the birth of our solar system.




Aluminum content of pyroxenes from LEW 86010 and a synthetic analog. The analog was prepared by melting material similar in bulk composition to LEW 86010, then cooling it slowly and allowing it to crystallize. The unusually high aluminum content of the natural pyroxenes is reproduced in the synthetic sample, suggesting that the high aluminum content of the melt , rather than unusual crystallization processes, is responsible for the aluminum enrichment. Pyroxenes in both samples show aluminum enrichment at the rims of the crystals, reflecting changes in the aluminum content of the melt during crystallization.

## Geochemical and Petrologic Studies of Planetary Differentiation on the Moon and Meteorite Parent Bodies

**PI: Marilyn M. Lindstrom/SN2**
**Reference SSS 3**

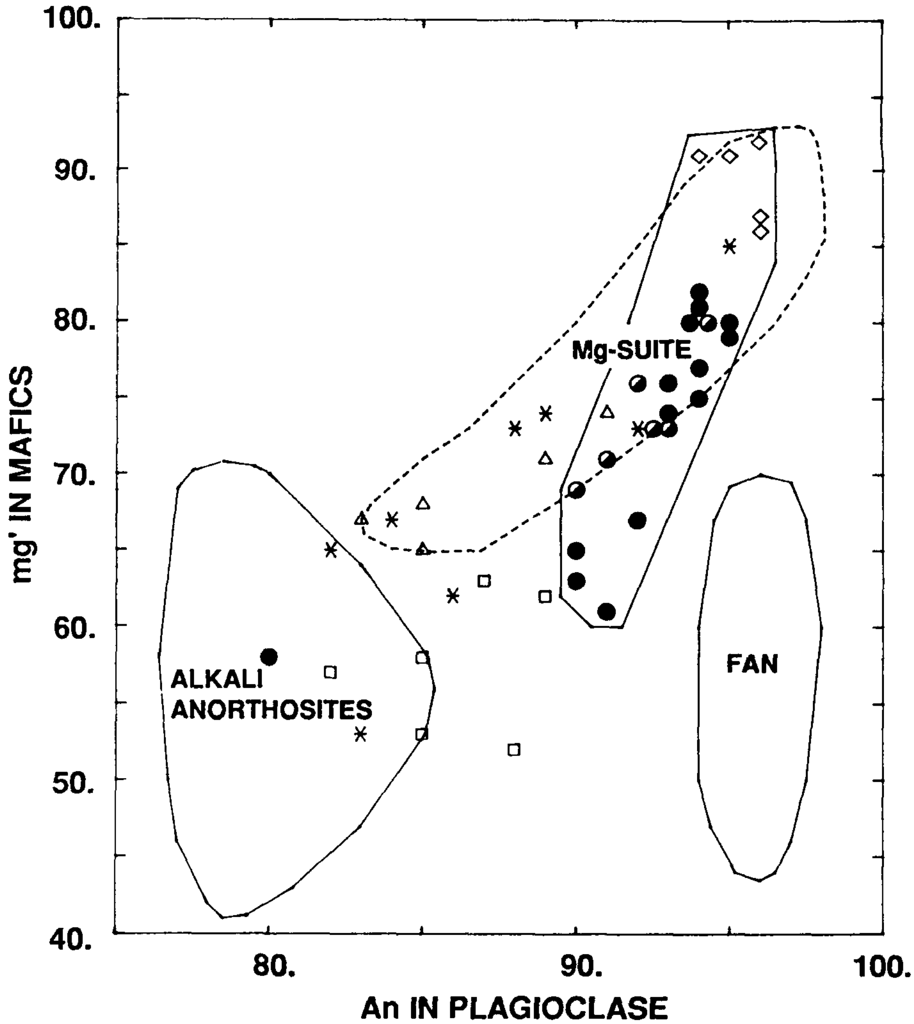
Planetary differentiation consists of various processes by which primitive matter in the solar system evolves into a variety of rock types. Differentiation has taken place on the planets, their moons and the parent bodies of some types of meteorites. The most common differentiation process is igneous differentiation which involves melting, crystallization, and separation into different rock types.

Our studies have focused on lunar samples and achondritic meteorites which exhibit a variety of compositions quite distinct from the chondritic meteorites thought to represent primitive solar system matter. Very early in its history, the Moon differentiated into a light-colored Ca-Al-rich anorthositic crust and a buried Fe-Mg-rich mafic mantle. Further differentiation in the mantle produced mafic intrusions buried in the crust and mare basalts, the dark-colored igneous rocks on the lunar surface.

During the past year, our lunar studies have focused on Apollo 15 samples excavated from some depth below the lunar surface. We have selected samples and analyzed them by instrumental neutron activation analysis and electron microprobe and have examined thin sections to evaluate texture and mineral composition. Our results have included three significant findings: We have identified several new members of the major suite of mafic intrusive rocks which redefine the differentiation trend for the suite. The figure is a plot of mineral compositions in the major lunar suites. The mafic suite is the Mg-suite near the top of the diagram. Two fields are drawn, the dashed field is the old trend which includes some unrelated rocks and the solid field is the new trend which includes the new samples and shows a steeper slope for the differentiation trend of this major suite.

Secondly, we have discovered a new type of lunar highlands rock, cordierite-spinel troctolite, and described its mineralogy and generation at a depth near the crust-mantle boundary. Most lunar samples are complex breccias and not the simple igneous rocks described above. The igneous rocks are very small and their compositions unrepresentative varying widely. We have identified numerous samples of a breccia whose composition is similar to the major igneous rocks, but less variable, and may represent the average composition of the deep lunar crust. All of these results will contribute to a better understanding of lunar differentiation.

We have also studied a group of meteorites thought to have come from the same parent body, the eucrites, diogenites, howardites and possibly related, mesosiderites. We have analyzed a large number of these meteorites including whole-rocks, minerals and clasts. We have extended the range for eucrite differentiation and found interesting complications in diogenite and mesosiderite petrogenesis. We concluded that eucrites, diogenites and howardites are from the same parent body, but are derived from a number of different parent melts, and that mesosiderites are probably from a distinct parent body.




Mineral compositions in the major lunar suites.

## Lunar Base Agriculture: Soils for Plant Growth

**PI: Doug Ming/SN14, Don Henninger/SN14, Reference SSS 4**

A bioregenerative Controlled Ecological Life Support System (CELSS) is a system where the crew is supplied with water, food, and oxygen that is produced by photosynthesis of living plants. The photosynthetic organisms (primarily plants and algae) consume carbon dioxide ($CO_2$), the major metabolic human waste, and combine it with water, converting these materials into food as well as producing the essential gas, oxygen. Development of such a CELSS is needed not only to allow for self- sufficiency but to reduce the transportation costs of resupply when the numbers of crewmembers rise above those required for an initial lunar outpost.

Growing plants at a lunar base has other attractive features beyond supply of food to lunar crews. Instead of resupplying food to Space Station Freedom (or future space stations) from Earth, re-supplying through lunar base agricultural production could reduce the transportation costs. Furthermore, industrial and human wastes from Freedom could be transported to the lunar surface where they could be recycled; thus, they become a resource available to lunar base expansion rather than a liability for Space Shuttle to return to Earth. Interplanetary spacecraft for human exploration will be extremely large vehicles requiring on-orbit assembly and supply due to their long-duration missions. Initial supplies of food could be provided from lunar base agricultural production. Waste products from the returning interplanetary spacecraft could be sent to the lunar surface for renovation and use.

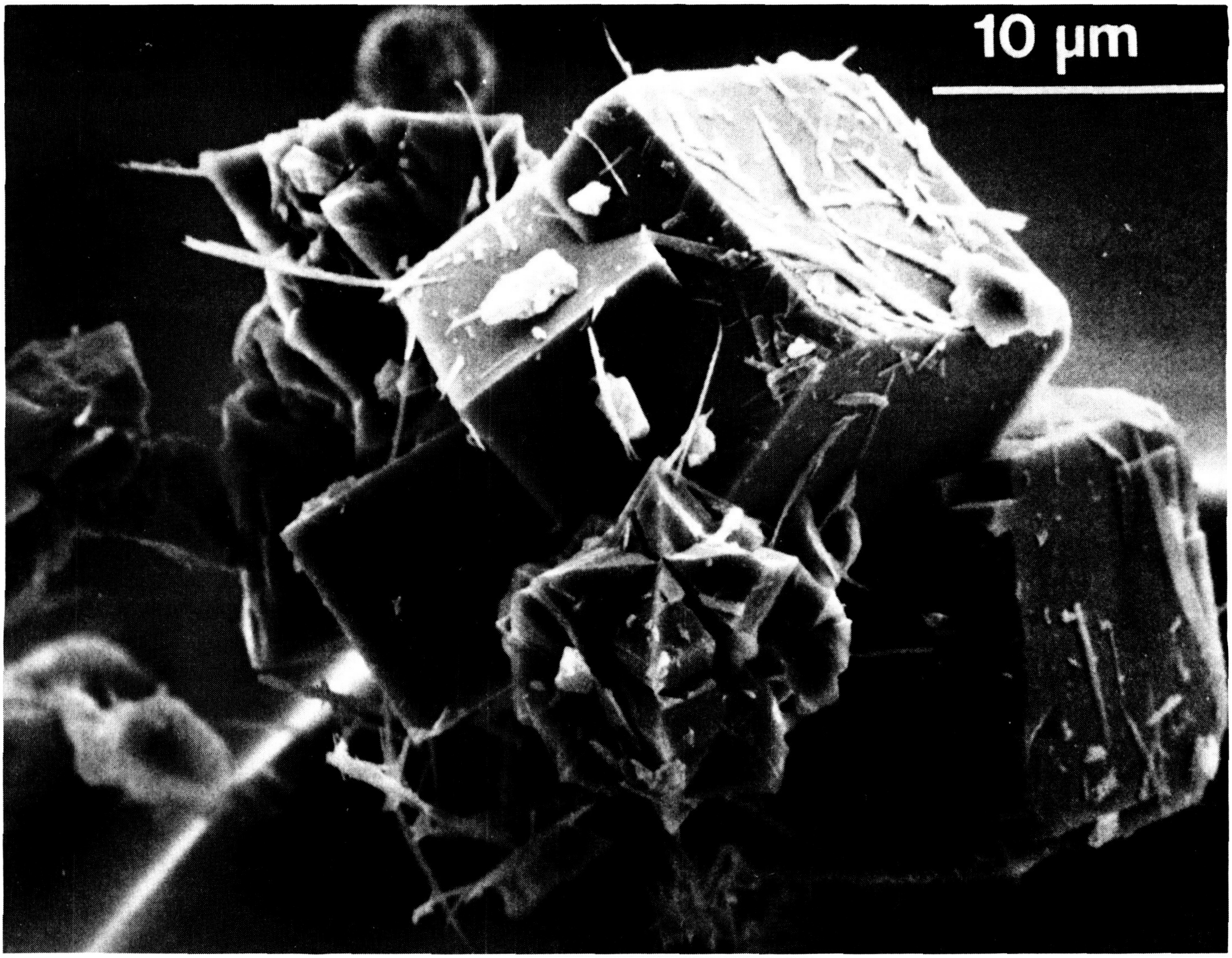
A self-sufficient lunar base will require the utilization of *in situ* resources for construction materials, propellents, life-support systems, etc. The growth of plants at a lunar base will be essential to sustain a self-sufficient human colony, and there are several systems in which to grow plants, e.g., hydroponics (plants grown in water) and solid-support substrates (or soils). Most of the plant-growth research in CELSS has been aimed toward hydroponic systems. Lunar-derived soils also may be viable plant-growth systems, however, our knowledge of how lunar materials will react as soil is limited.

The ultimate goal of this proposed research is development of a lunar-derived soil for the growth of plants at a human-occupied lunar base; a soil very much like those of Earth--highly productive, stable, resilient, and psychologically pleasing. Such a lunar agricultural soil would then become a central component in the life support system at the lunar base, functioning in food production and most likely in air and waste renovation as well. The specific objectives of this research are as follows:

- Examination of unaltered lunar regolith as a soil;
- Investigation of the synthesis of a highly-productive solid- support substrate for plant growth;
- Preparation and characterization of lunar simulants that may be used for plant growth experiments;
- Conduct plant growth experiments in various prepared solid-support substrates.

To date, several synthetic soil materials have been prepared from lunar regolith simulants. These materials have the ability to exchange some of their constituent ions (e.g., plant-essential elements) into soil solution. This process is known as ion exchange. Ion exchange materials increase the plant nutrient retention in growth mediums and, thus, increase the overall productivity of the plant growth substrate. The primary materials synthesized from the lunar simulants are a group of minerals known as zeolites. Zeolites are some of the most effective ion-exchange materials known. These synthetic minerals were easy to synthesize under relatively mild temperatures and pressures.

In the coming year, we will begin plant growth experiments in various zeolite substrates. Also, we will examine the release of plant-essential elements from lunar regolith simulants to assess the feasibility of using lunar materials as plant-growth substrates. We will continue to improve the fidelity of the lunar simulants used in these experiments and will eventually subject actual Apollo-returned lunar samples to the experimental regime.




Scanning electron micrograph of Zeolite A (twinned cubes in upper-center of micrograph) and Zeolite $P_t$ (bipyramidal-like crystals in lower-center of micrograph). These Zeolites were synthesized under ,mild hydrothermal conditions from synthetic basaltic glass with chemical compositions analogous to basaltic glass of the lunar highlands. Zeolites are highly reactive minerals that will act as highly-productive solid-support substrates for plant growth at a lunar base. The use of synthetic zeolites at lunar bases will not be limited to agricultural purposes. Based on their unique adsorption, hydration/dehydration, molecular-sieving, ion-exchange, and catalytic properties, synthetic zeolites may be used as adsorption media for the separation of gases, as catalysts, as molecular sieves, and as cation exchangers in sewage-effluent treatment, in radioactive waste disposal, and in pollution control.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

## Discovery of Sodium and Potassium Vapor in the Atmosphere of the Moon

**PI: A. E. Potter/SN3**
**T. H. Morgan/SN3**
**Reference SSS 5**

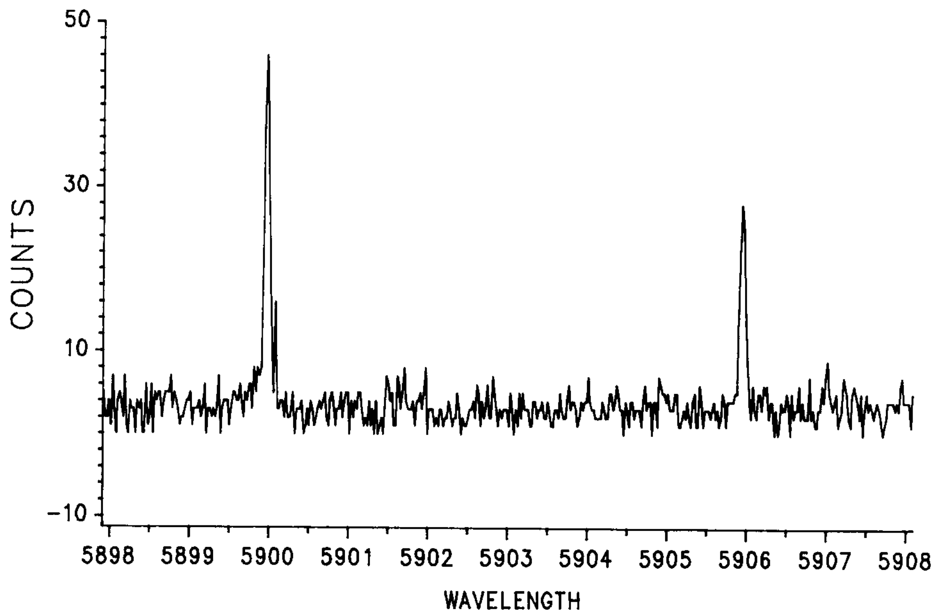
In 1985, we discovered sodium vapor to be one of the dominant species in the atmosphere of Mercury, and followed with the discovery of potassium vapor in the next year. These metal vapors were observed by resonance scattering of sunlight from the atoms, which is a remarkably sensitive method for detection of sodium and potassium vapors. The origin of these elements in Mercury's atmosphere could be explained by meteoric impact on the surface, by solar wind sputtering of the surface, or by a combination of these factors.

It was natural to extend these concepts to the Moon, and the analysis of the lunar case showed that sodium vapor should exist in detectable amounts in the atmosphere of the Moon. Surprisingly, very little is known concerning the lunar atmosphere. Measurements during the Apollo program showed the total daytime pressure was found to be of the order of $10^6$ atoms/cm$^3$, but the composition of the atmosphere was not measured. (It should be noted that the lunar "atmosphere" corresponds to a very good vacuum in the laboratory, of the order of $10^{-14}$ atmosphere.) Consequently, there was no evidence against the existence of sodium vapor in the lunar atmosphere.

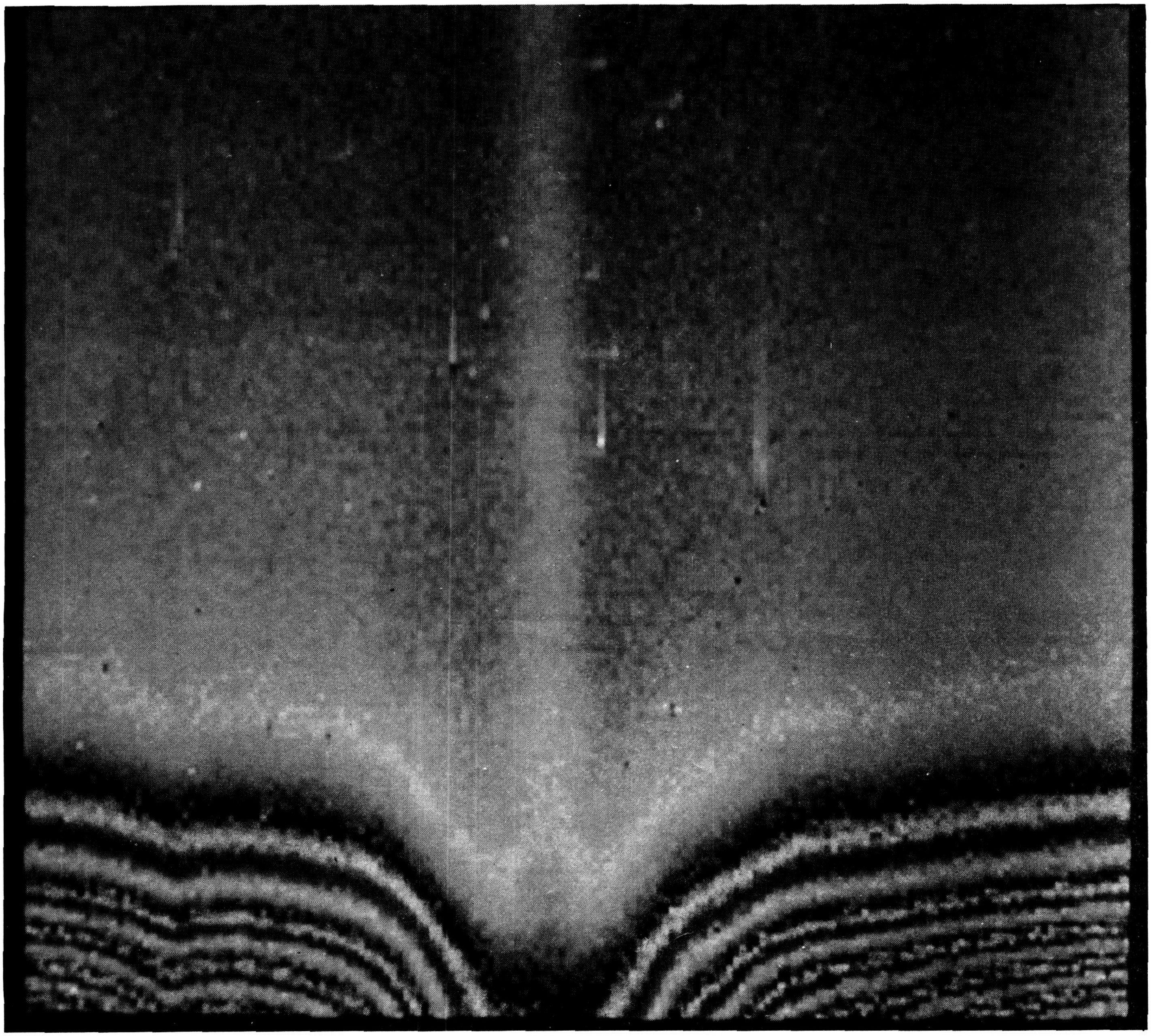
We searched for sodium in the lunar atmosphere by means of high resolution spectroscopy, and indeed, spectra of the region just above the edge of the Moon showed weak emission features from resonant scattering of sunlight by sodium and potassium vapor at the sodium $D_2$ and potassium $D_1$ lines.

The omnidirectional emission flux above the lunar surface was 3 to 4 kilorayleighs for sodium, and 1 to 2 kilorayleighs for potassium. The sodium emission, for which there are now more observations, has been found to extend to the poles and many hundreds of km above the surface. The surface densities of sodium and potassium are $67 \pm 12$ and $15 \pm 3$ atoms/cm$^3$, respectively. The ratio of the density of sodium in the lunar atmosphere to the density of potassium is about 6 to 1, which is close to the sodium/potassium ratio in the lunar surface minerals, suggesting that a large part of the material is derived from the surface by meteoric impact and/or solar wind sputtering.

The capability to map and monitor the sodium and potassium exospheres of the Moon using ground-based telescopes should lead to a significantly better understanding of the lunar atmosphere, as well as the similar atmosphere observed for Mercury.




**Emission in the sodium resonance lines 600 km above the bright limb of the Moon.**



An image of the subsolar limb of the Moon in the spectral region of the sodium $D_2$ line at 5889.7 Å. The length of the vertical axis is 28 arcseconds (0.14 arcsecond per pixels), while the length of the horizontal axis is 2.16 Å (5.4 mÅ per pixel). The edge of the Moon is at the bottom. Above the lunar surface, centered on the solar sodium Fraunhofer absorption minimum, a weak emission line extends to the top of the image. The line is sodium resonance radiation, produced from the scattering of sun-light by sodium vapor in the lunar atmosphere.

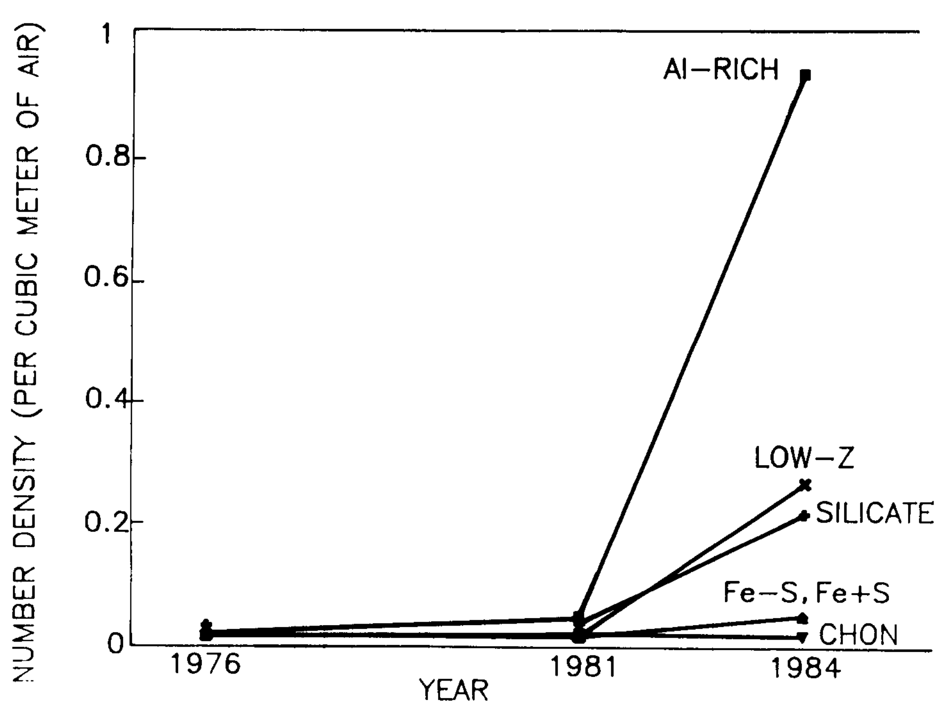
## How Crowded is Space? Measuring the Amount of Extraterrestrial Material Falling to the Earth

**PI: Michael Zolensky**
**Planetary Science Branch**
**Reference SSS 6**

In addition to our ongoing research to characterize meteorites and interplanetary dust samples, we need also to learn what amounts of these primitive solar system materials are present in the near-Earth environment. These studies will help us in devising realistic models of the evolution of our solar system and the bodies in it, as well as serve as inputs into the design of spacecraft. Our work has concentrated on materials in two vastly different mass ranges: Meteorites, with masses ranging upwards from 1 gram, and interplanetary dust, with typical masses of $10^{-7}$ to $10^{-9}$ gram. By measuring the amount of material in these two different mass ranges, and interpolating between these values, we will obtain a reasonable estimate of the total mass of extraterrestrial material that falls onto the Earth.

We have directly measured the amount of interplanetary dust falling to Earth, by catching it before it lands. We fly interplanetary dust collectors aboard NASA U-2, ER-2 and WB-57 high-flying aircraft. The dust is collected in the stratosphere, and returned to the Curatorial Facility Class 100 clean rooms at the Johnson Space Center. In this ultra-clean facility the captured particles are removed for detailed analysis. In this way we analyzed particles collections made in 1976, 1981 and 1984. The graph shows the amounts of different particles types conveniently plotted as number density of each particle type per cubic meter of air. Interplanetary particle types include chondritic (CHON) and iron-rich particle types (Fe + S and Fe-S). The amount of each of these particle types is typically ~0.01 particle per cubic meter of air, a value which is not observed to vary from 1976 through 1984. However, a very different picture emerges for particles rich in silicates (SILICATE), aluminum (Al-RICH) and carbon (LOW-Z). These particle types, which are typically ablation products of spacecraft, are observed to greatly increase in volume between 1981 and 1984. We have concluded that this effect has resulted from the creation and continued evolution of the belt of manmade debris in low Earth orbit. We thus conclude that any potential hazard to spacecraft represented by interplanetary dust particles is greatly overshadowed by particulates of manmade origin.

The discovery and characterization of 154 meteorites recently found within a small (11 km$^2$) area of Roosevelt County, New Mexico, is permitting us to measure the yearly number of meteorite falls over the last 16,000 years. A fortunate set of geological and meteorological circumstances has resulted in the preservation of the complete meteorite fall record for this area. Modern thermoluminescence dating techniques have been applied to the dating of the period of time these meteorites have resided on the Earth. When we compare our results with previous determinations of the current infall rate of meteorites we observe that our result (which covers that last 16,000 years) is approximately an order of magnitude higher. One possible conclusion from this study is that the present infall rate of meteorites is far lower than the average value for the past 16,000 years. We are presently exploring the implications of this intriguing result. When we have combined this new meteorite infall rate for meteorites with our above results for interplanetary dust particles we will be a major step closer to understanding the current state of our solar system.




**Results of dust-collection experiment to determine particle density.**

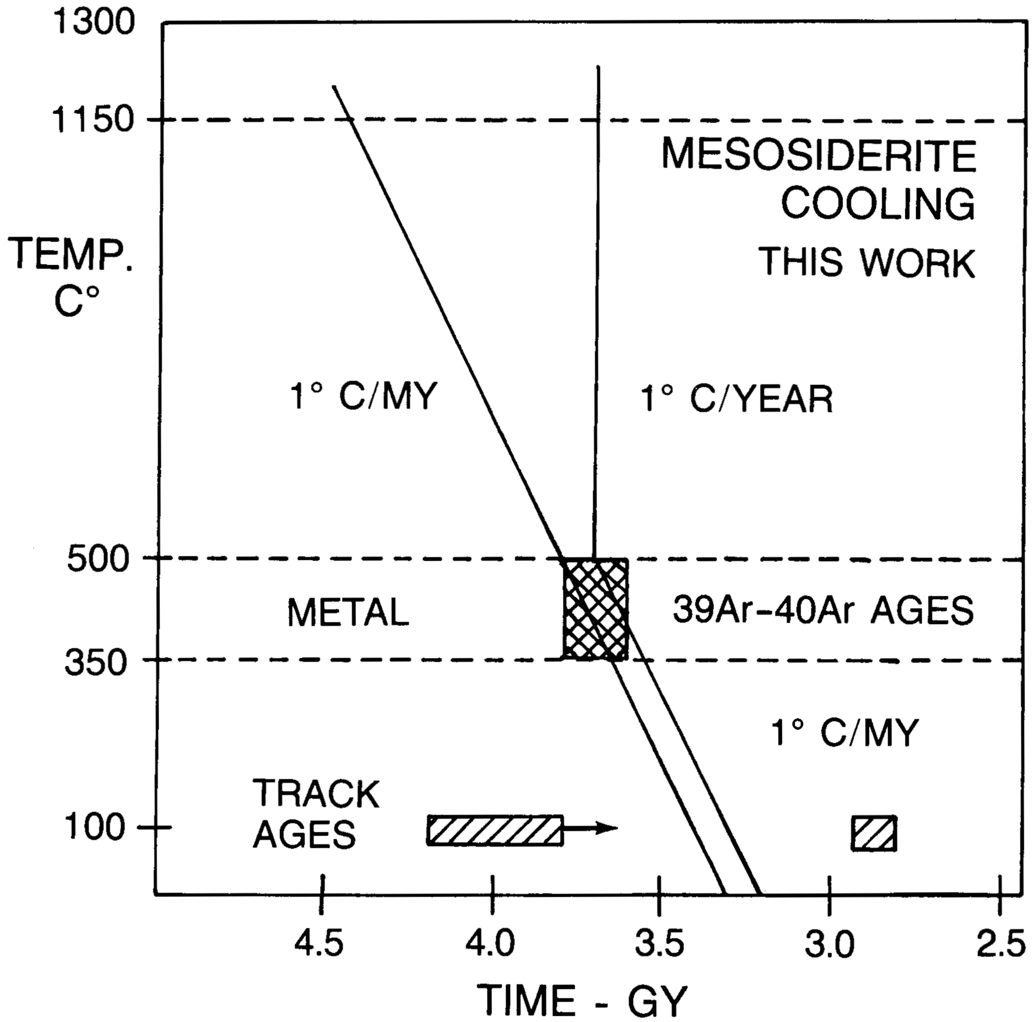
## Age Dating of Mesosiderites: Evidence for Major Parent Body Disruption Less Than 4 Billion Years Ago

**PI: Donald Bogard/SN2**
**David Mittlefehldt/SN2**
**Reference SSS 7**

Mesosiderites are basaltic regolith breccias which experienced metal-silicate mixing, probably when the metal was molten. Nickel zoning in the metal and the abundance of tetrataenite suggests that this phase cooled slowly, about 0.5-1 degrees C per million years (My), suggesting burial depths of up to tens of kilometers in a relatively large, asteroidal parent body. Several theories have been offered for mesosiderite origins. Most assume that brecciation and silicate-metal mixing occurred early in solar system history, and that the slow metal cooling rates were produced by deep burial processes such as crust-core layers. The apparent incompatible characteristics of slow cooling of the metal, suggesting deep burial, and brecciated nature, suggesting a surface origin, are not readily explained by any one model for mesosiderite origin. A chronology of events should be valuable in understanding mesosiderite origin and history. However, only a modest amount of published chronological data is available on mesosiderites. Among these data are a 4.24 ± .03 Gy Rb-Sr isochron for Esterville, several classical K-Ar ages (with K and Ar not measured on the same sample) that ranged 3.2-4.25 Gy, and 244Pu fission track ages for six of ten measured mesosiderites of 3.9-4.2 Gy.

We have determined 39Ar-40Ar ages for 11 samples of 9 mesosiderites, which include all four of the classified metamorphic groups (modestly recrystallized to melted matrix) and both of the mineral groups (pyroxene or feldspar dominant). Ages of 39Ar-40Ar for all samples indicate Ar loss by one or more events more recently that 4.0 Gy ago. A few samples gave reasonably well-defined plateau ages of approximately 3.6 Gy. A few other samples gave ages that start at approximately 3.6 Gy at low extraction temperatures and increase to ages of 3.8-4.0 Gy. One sample indicates major loss of Ar by an event approximately 2.7 Gy ago, but Ar released at higher temperatures suggests an age of ~3.6 Gy. None of the 11 analyses show significant evidence for 39Ar-40Ar ages older than 4.0 Gy. Most analyses, however, are consistent with one or more heating events approximately 3.6-3.8 Gy ago. Ar was released from these samples at relatively high temperatures. Closure temperatures calculated from our diffusion data indicate that Ar diffusion loss would have ceased at ~350-500 degrees C for cooling rates of ~1degrees C/My, which is the same temperature region where Ni diffusion profiles were established. The Ar ages thus determine the time of establishment of Mi cooling rates to have been ~3.6 Gy ago.

The ~3.6-3.8 Gy 39Ar-40Ar ages found for mesosiderites would appear to rule out those models that form mesosiderites at ~4.5 Gy, followed by relatively rapid cooling to ~600 degrees C, then cooling at ~1degree C/My through the ~500 degrees C region to establish Ni cooling rates. The 39Ar-40Ar ages could be interpreted in one of two other ways. After mesosiderite formation ~4.5 Gy ago, the metal-silicate mixture cooled slowly, deep inside a parent plant, until both the Ni cooling rate textures and K-Ar ages were established at ~500-350 degrees C, ~3.6-3.8 Gy ago. This interpretation suffers several disadvantages: It would require slow cooling of silicate at higher temperatures (>700 degrees C), counter to petrographic observations; it would require deep burial in an unusually large parent body to sustain slow cooling over ~1 Gy; and it probably would be difficult to account for the significantly older Rb-Sr ages if mesosiderites were held at high temperatures for millions of years. A second model to explain available data is that a catastrophic collision of two asteroids, ~3.6-3.8 Gy ago caused disruption of the mesosiderite parent body and subsequent deep burial when the material gravitationally reassembled. A similar model has been offered to explain observed thermal histories of chondrites. With this model, mesosiderite cooling would have been rapid at high temperatures, but post-assembly cooling at a rate of ~1 degree C/My below ~550 degrees C would have caused resetting of K-Ar ages and would have established the Ni cooling rates. Although we favor the latter model, either of these two models of mesosiderite origin requires a complex history involving deep burial in a parent body and establishment of the Ni cooling rate at a time dated by the 39Ar-40Ar ages.




Two models for mesosiderite silicate-iron mixing and thermal cooling. Both models begin with initial temperatures above 1150 degrees C, and both satisfy the constraints placed by $^{39}Ar/^{40}Ar$ ages that the cooling passed through the 350 to 500 degrees C temperature interval 3.6 to 3.8 Gy ago. One model calls for cooling at a constant rate of 1 degree C/My, and would require a very large parent body. The other model calls for rapid cooling to above the temperature regime where metal textures were formed, followed by 1 degree/My cooling to satisfy the metal data. This second model would require a catastrophic event such as parent-planet breakup and gravitational reassembly to achieve metal-silicate mixing.

# Space Transportation Technology

## Summary

ORIGINAL PAGE IS
OF POOR QUALITY

PRECEDING PAGE BLANK NOT FILMED

PAGE 86 INTENTIONALLY BLANK

## Office of Space Flight

The Office of Space Flight Advanced Program activities are primarily directed toward enhancing and expanding the National Space Transportation System (NSTS), focusing on advanced means of transportation, and providing a technical base for planning extended space exploration.

During this past year, the majority of the Johnson Space Center's work has been directed to NSTS activities. However, with the successful flights of STS-26 and 27, JSC can once again set its sights on the improved capability of the NSTS to access the space environment and human exploration of the solar system.

### Advanced Transportation

The advanced transportation activities currently underway at JSC encompass a wide variety of work, ranging from enhancements of the existing NSTS, to a space transportation system that would establish a lunar outpost in the year 2005.

As part of the NSTS enhancement efforts, JSC is conducting a Space Shuttle Evolution Study. The objective of this task is to develop strategies for evolving or modifying the Space Shuttle which will increase crew safety, reduce costs, and increase system capability. All elements of the Shuttle system are included in the evolution process (hardware and operations). Significant accomplishments include: development of the Space Shuttle Enhancement Data Base; implementation of Shuttle Evolution working groups; and, identification of near, interim, and long term goals.

JSC is investigating an approach to increase the Space Shuttle Orbiter performance by uprating the Orbital Maneuvering System (OMS) engine. The approach involves the use of a gas generator-driven turbopump to operate at conditions which effect a significant increase in engine-specific impulse, thereby enhancing performance. Uprated engine performance translates into im- proved intact ascent abort capability and increased on-orbit payload and altitude capability for the Space Shuttle. Full-scale hardware tests have demonstrated the projected performance gains, and studies have confirmed the feasibility of retrofitting the new engine into the Orbiter.

JSC is working on a conceptual design of a Personnel Carrier Shuttle II. The purpose of this shuttle vehicle would be to rotate Space Station crews. Design requirements called for the vehicle to be fully reusable, to return to Earth by landing on a runway, and to provide crew escape capability during all phases of ascent and descent. It was assumed that Space Station crew size would be limited to eight people and that two crew members were required to pilot the vehicle. This study was intended to address a winged vehicle concept. Previous NASA studies had already examined lifting-body concepts and ballistic entry vehicles to rotate Space Station crews.

In conjunction with the advanced Space Shuttle work, JSC is developing an Earth-to-orbit launch vehicle sizing program which will utilize weight estimation relationships. The program will account for velocity losses for different thrust-to-weight ratios at liftoff and staging, and aerodynamic losses for changes in vehicle area. The Earth-to-orbit vehicle program was developed for use on desktop computers. The model utilizes weight estimation relationships for both the booster and second stage elements. Parametric trajectory data was developed to account for various thrust-to-weight ratios at liftoff and staging, and for changes in the surface area of the launch vehicle. The model is designed for easy modification and can be used for other launch system sizing studies.

JSC has continued to define the characteristics of a simplified Crew Emergency Return Vehicle (CERV) that would return Space Station crewmembers to Earth in an emergency requiring immediate evacuation. The objective of the study was to design a vehicle with high reliability and low maintenance that incorporated simple, passive systems where appropriate. The Station Crew Return Alternative Module (SCRAM) was the result obtained from the mission requirements and the design philosophy used in the simplified CERV study. The crew module is sized for six crewmembers, for a total mission duration of 3 hours.

A number of related tasks are being pursued which focus on the human exploration of the solar system. To meet this challenge, JSC is conducting an in-house and contractor supported Lunar Base Systems Study. This study outlines a lunar outpost to be established in the year 2005 and the associated space transportation system. Transportation elements such as a Transportation Node in low Earth orbit, and Orbital Transfer Vehicle to bring payloads to lunar orbit, and a Lunar Lander have been defined. Reference missions and operational scenarios for these vehicles have also been defined, as well as the Earth-to-orbit launch requirements to support them. A series of orbital trajectory programs with documentation were developed. These programs will be used in future lunar base studies.

### Advanced Operations

Training is a major effort at all NASA operational centers and has high direct and indirect costs. In addition, most critical training is obtained in an "on-the-job" setting. Such training depends on the availability of experienced personnel and is generally

inefficient. Current studies at JSC have investigated the application of artificial intelligence technology to the development of autonomous intelligent training systems. The first product of this effort was an Intelligent Computer-aided Training (ICAT) System for Shuttle flight controllers who guide the deployment of satellites. The ultimate goal of this project is to develop a general purpose software environment for the production of ICAT applications. Additional applications are being developed to demonstrate the applicability of ICAT systems in a variety of domains and to refine and extend the current architecture. These applications will serve as platforms for designing and developing a set of software tools for the production of ICAT systems for use in all NASA centers as well as other government agencies, the military, and the private sector.

Software development is a serious obstacle in the construction of complex systems. An increase of the reuse of software designs and components has been viewed as a way to relieve this bottleneck. One approach to achieving software reusability is through the development and use of software parts composition systems. JSC is currently working on an Advanced Software Development Workstation (ASDW) Project to investigate ways to use knowledge representation, retrieval and acquisition techniques, to reduce the amount of manual effort spent in the creation of similar systems. During the past year, considerable progress was made in the development of the information retrieval system which uses a technique called specification-by-reformulation. This technique is based on a cognitive theory of retrieval from very-long-term memory in humans.

During the past year, JSC began developing a Integrated Autonomous Flight Operations Functional Simulation. This software test bed, called AUTOPS (Autonomous Operations) is being developed to support systems analysis and to evaluate autonomous on-orbit operation during space flight. The test bed uses a variety of technologies and techniques to implement mission planning and monitoring functions, fault detection and recovery activities, sensor and subsystem data processing, and guidance, navigation, and control functions. AUTOPS will support a wide variety of spacecraft and robotic manipulators. The test bed will permit evaluation of various control systems, including expert systems and fuzzy logic controllers, and their interactions with simulated vehicle components. The products of such evaluations are sets of rules, fuzzy set definitions, or procedural programs that would be incorporated into autonomous vehicle systems. A final goal of the test bed is to have real-time operation. This will allow a user to observe the effect of decision-making time on the quality of automation that can be obtained, to evaluate the interactions between coordinated or cooperating intelligent systems, and to determine any anomalous effects due to sensor sampling times or delays in system interactions with a simulated space environment.

Under a separate but related effort to the AUTOPS test bed project, JSC has begun developing expert systems for diagnosing malfunctions and for planning and executing recovery from them, in an electric power system and a propulsion system. These systems represent two of the numerous systems required to maintain space vehicle operation under autonomous control. After the capability is developed to do the diagnosis and recovery for each system individually, they will be combined to cooperate to assure that the recovery implemented is consistent with mission objectives, plans and timing as well as being a consistent and correct solution to the problem producing symptoms detected by the various troubleshooting experts.

JSC continues to develop the requirements for a fuel- optimal Autonomous Ascent Guidance system. The system will satisfy all launch vehicle attitude and trajectory constraints within an uncertain day-of-launch and systems performance environment. This system will result in reduced operations costs by eliminating many preflight activities as well as increased safety and reliability by adapting to in-flight dispersions. The 1988 activities included: investigating mission operations of the STS program, developing prototype guidance systems, and investigating new hardware requirements.

**Satellite Services**

Satellite Servicing is an evolving technological activity currently in the early stages of development. NASA on-orbit experience, ranging from initial attempts to service early in the manned space program to present day planning provides the data for future capabilities. Today the satellite servicing base includes the existing Space Transportation System and the planned Space Station. Servicing support equipment and tools have evolved from prior experience. Future development of telerobotic and robotic servicing capabilities will evolve to meet user needs. The NASA goals are to baseline generic servicing equipment and to standardize the servicing interfaces, thus allowing satellite developers to consider servicing in their original design phase. Major activities conducted in 1988 include meetings and publications of the JSC Satellite Services Working Group which provide the satellite designers and satellite users a forum and information to establish the requirements and conduct studies for the development of servicable satellites.

Studies of the on-orbit refueling market reveal the need for superfluid helium (SFHe) resupply in the 1998 time frame. One application of SFHe is the cooling of detectors and other electronic sensors. The low temperature reduces thermal noise and provides a constant temperature environment for the sensor. In devices using superconduction to achieve high-magnetic fields, SFHe is used for its heat transfer characteristics. Examples of such devices are semiconducting particle detectors and large-scale infrared detectors for astrophysical studies. The Johnson Space Center is responsible for the definition and development of orbital resupply tankers. System studies and prototype hardware development activities have been per- formed to determine the best approaches to be taken for the resupply of numerous fluids and gases. The unique characteristics of SFHe result in the need for radically different approaches to the design of certain subsystems for space transfer of this fluid. Work is currently being done on the development of an Earth-storable tanker and superfluid helium tankers. The objective of this work is to develop a coupling for the transfer of SFHe during Superfluid Helium On-Orbit Transfer flight experiment. This flight experiment is being managed by the Goddard Space Flight Center (GSFC) and is designed to simulate a satellite reservicing operation. The JSC is responsible for the fluid coupling development as well as coordinating the EVA activities for this flight experiment.

Efforts are continuing at JSC to develop vision systems and/or tracking sensors to accurately identify targets or target features and determine their position and attitude. One project that implements a combination of sensors is the Extravehicular Activity Retriever (EVAR). This is a three-year/three-phase ground demonstration of a concept that will result in a robotic system concept to retrieve loose objects in space, from a dropped tool to a disabled astronaut. The system consists of a Manned Maneuvering Unit with a robot body attached, including two robotic arms. A target recognition/tracking system using a video camera as its sensor provides the capabilities to pick out simple shapes from a scene by using voice commands, lock on and track the specified object and give position information for rendezvous.

Studies of populations and hazards of orbital debris continue at JSC. During the past year, a significant change has been made in the orbital debris model, based on new data and new calculations. The new model predicts an environment in the 1-2 centimeter size range that is a factor of 2 to 10 times larger than previous prediction. This will have a significant effect on Space Station design.

# Space Transportation Technology

## Significant Tasks

## Shuttle Performance Enhancement Using an Uprated OMS Engine

**PI: C. Mallini/ED2**
**W. Boyd/EP4**
**Reference STT 1**

The baseline Orbital Maneuvering Engine (OME) of the Space Shuttle has the potential for significant performance uprating, leading to increased Space Shuttle operational flexibility. The Johnson Space Center (JSC) is investigating an approach to OME uprating which involves the use of a gas generator-driven turbopump to operate in conditions which effect a significant increase in engine-specific impulse, thereby enhancing performance. Full-scale hardware tests have demonstrated the projected performance gains, and studies have confirmed the feasibility of retrofitting the new engine into the Space Shuttle Orbiter. Uprated engine performance translates into enhanced intact ascent abort capability and increased on-orbit payload and altitude capability for the Space Shuttle.

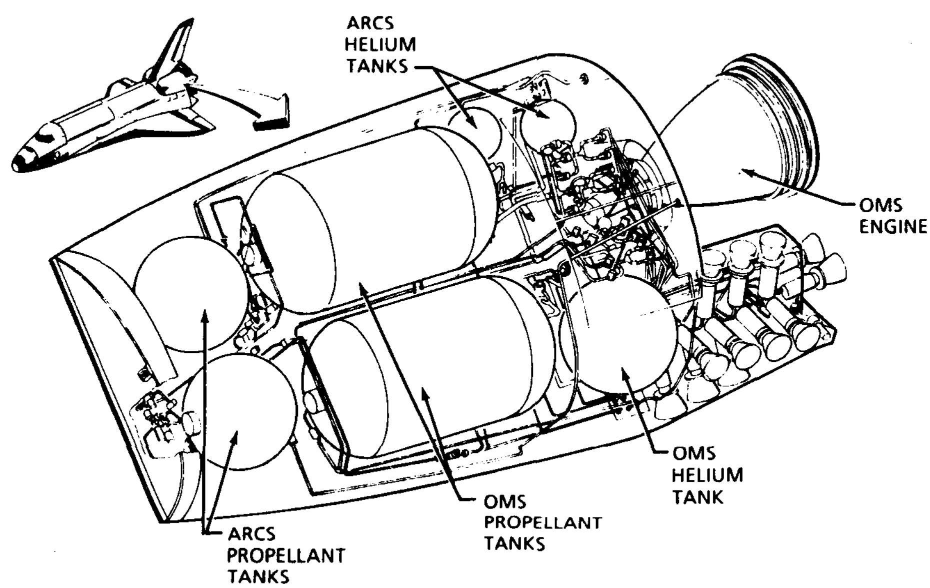
The results of this study indicate that performance improvements are not limited to payload mass to orbit. In fact, the increased Isp of the uprated OME can be converted into a combination of enhancements: increased on-orbit $\Delta v$, increased payload mass to orbit, and increased MPS propellant margin.

MPS propellant margin can be used to improve ascent abort capability. Ascent abort performance is enhanced for the abort-to-orbit and the abort-once-around. SSME fail times for these two abort mode boundaries are extended by 3.1 to 3.5 seconds. The SSME fail time for the press-to-MECO boundary is extended by over 5.5 seconds. This additional coverage translates into a higher probability of mission success.

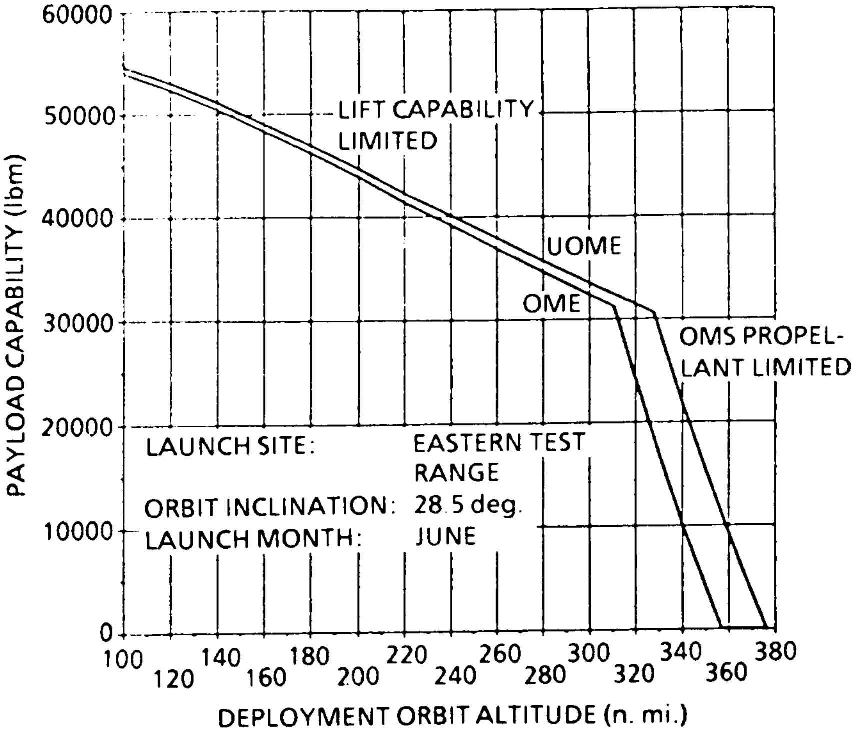
On-orbit $\Delta v$ and payload mass to orbit are improved. Increased on-orbit $\Delta v$ can be used to increase operational flexibility in a variety of ways: higher deployment, reboost, and servicing altitudes. For on-orbit delivery missions to altitudes below 310 n. mi., increases of up to 1,200 lbm in payload or 10 n. mi. in altitude can be obtained. For altitudes above 310 nmi, increases of 12,000 lbm in payload or 20 n. mi. in altitude can be achieved.

It was shown that the extended capability can enhance on-orbit operations, this includes extending the time between reboosts for a long duration payload such as the Hubble Space Telescope (HST). This additional time can then be used to provide flexibility in manifesting the follow-on HST reboost mission on the Space Shuttle.

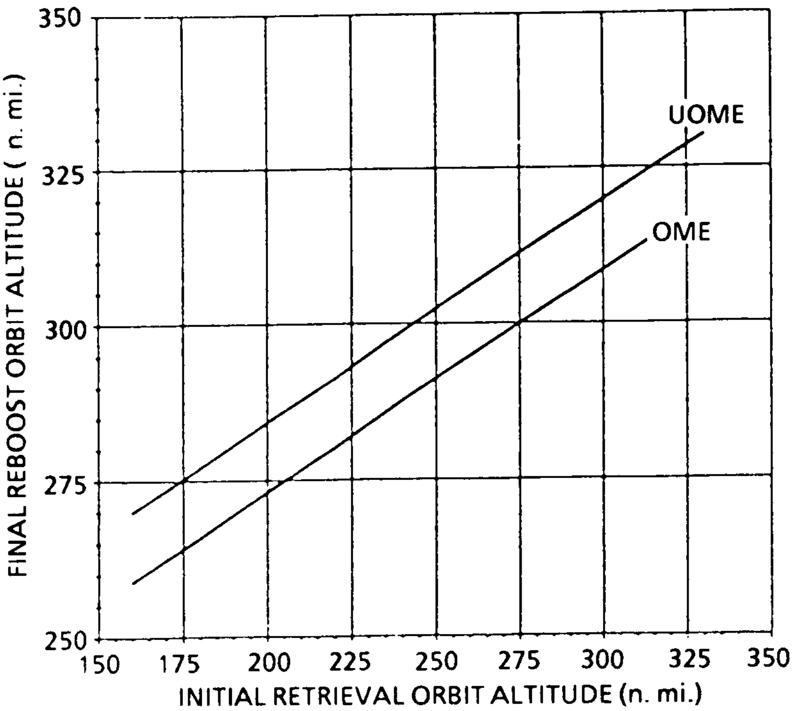
The worth of the uprated OME cannot be measured by increased payload mass to orbit alone. the additional performance provided by the engine enhances all phases of the Space Shuttle mission which require the use of the OMS.




**Space Shuttle Orbital Maneuvering System.**




**Typical Space Shuttle payload deployment/altitude performance envelope.**




**HST reboost capability.**

## Uprated OMS Engine for Upper Stages

**PI: William C. Boyd/EP4**
**Reference STT 2**

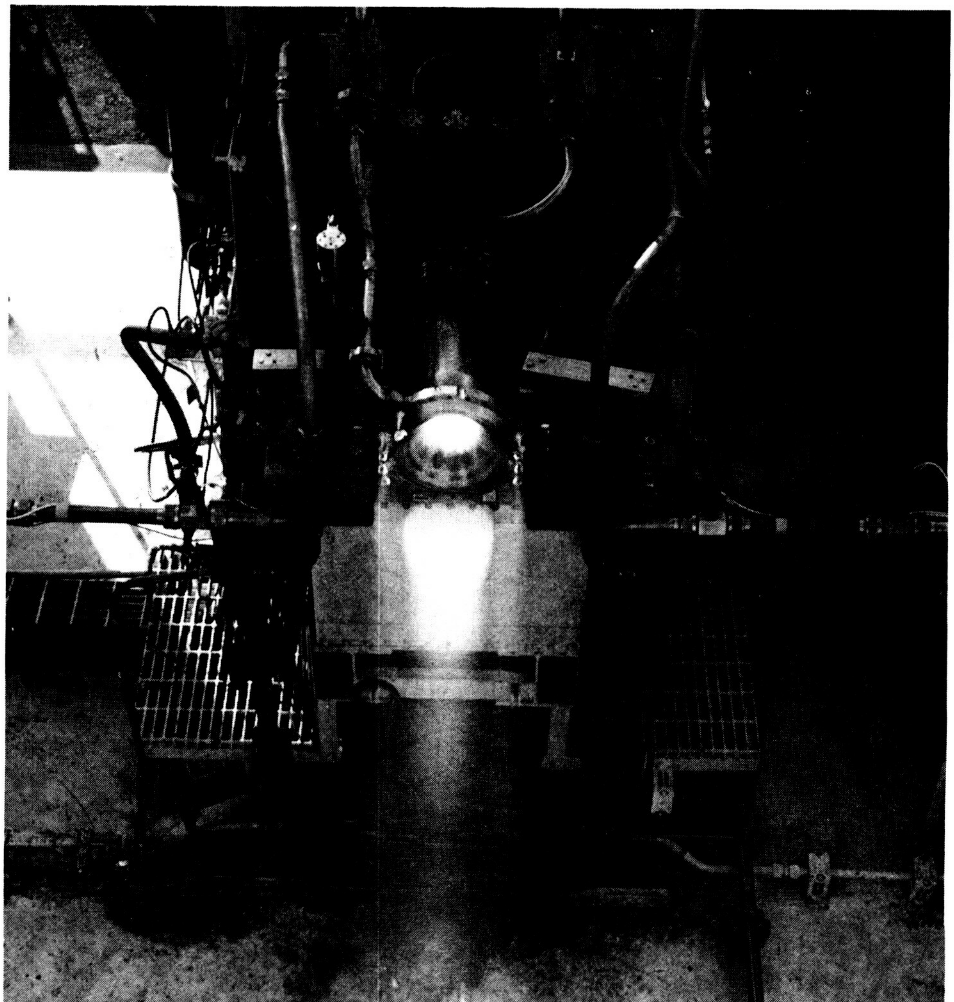
The Space Shuttle Orbital Maneuvering System (OMS) is a pressure-fed propulsion system that utilizes the storable propellants, nitrogen tetroxide and monomethylhydrazine. An uprated pump-fed version of the OMS Engine (OME) can provide significant benefits for the National Space Transportation System (NSTS), including increased Space Shuttle Orbiter payload and altitude capability, and a high performance man-rated engine for upper stage applications.

Development of a high performing upper stage for use in the Space Shuttle would be a natural and logical expansion of the satellite placement service currently being provided by the NSTS, and may be a key factor in the economical and practical commercial development of space. It is clear, however, that Space Shuttle safety and satellite delivery reliability are themselves prime factors in the future development of a means for delivery of today's complex and costly satellites.

Recent Air Force sponsored studies have shown that an upper stage using nitrogen tetroxide and monomethylhydrazine can provide the high performance and reliability required for future satellite delivery missions, as well as meet Space Shuttle safety requirements when delivered to low Earth orbit (LEO) by the Space Shuttle. Use of these storable propellants also allow long orbit stay times not compatible with cryogenic propellant stages, and extreme mission flexibility not available with solid propellant stages. Their excellent bulk density results in much shorter stage lengths than achievable with cryogenic stages.

The objectives of the Uprated OMS Engine (UOME) advanced development program are to conduct the analysis, design, fabrication, and test efforts necessary to demonstrate the performance and operational goals of a complete high performance pump-fed version of the Space Shuttle OMS Engine. As the latest state-of-the-art in pump-fed storable propellant rocket engines, the UOME has become a leading candidate for future space satellite delivery to geosynchronous Earth orbit (GEO), and its combustion chamber pressure of 350 pounds per square inch allows the use of conventional materials and cooling techniques, thus providing a high level of operational reliability. Many of the components of the engine are taken directly from the existing pressure-fed OME, including the main propellant valves, gimbal ring and actuators, wiring harnesses, and several control valves. The remaining critical components utilize existing technologies so as to minimize engine development risk.

Pre-development activities since FY85 have verified the performance capabilities of the critical components, including the turbopump, gas generator, and main combustion chamber injector. The accomplishments during FY88 include fabrication and test of a regeneratively fuel-cooled combustion chamber, and assembly of the various components into an integrated engine. Hot fire testing will verify that the critical engine components can be operated together as a system. Tests at ground environment conditions are planned for January of 1989, with tests at simulated altitude conditions planned for November of 1989 at the NASA White Sands Test Facility.



Hot fire test of the uprated OMS engine thrust chamber assembly.

## On-Orbit Compressor Technology Program

**PI: John P. Masetta/EP4**
**Reference STT 3**

The requirements for a wide range of gases, gas mixtures, and operating conditions have been identified for various space station and related on-orbit fluid systems operations. The practical use of these systems for fluid storage and transfer will require compressors capable of long-term on-orbit operations over this entire range of requirements.

The objective of this program is the exploration of compressor technology (designs, materials ad manufacturing techniques) applicable for use by the Space Station Fluid Management System, the Space Station Propulsion System, and the Orbital Spacecraft Consumables Resupply System. The approach is to develop a conceptual design applicable to seven different applications and to develop a prototype design for one specific application. The prototype development will consist of a detailed design for the prototype conditions based on the general conceptual design, fabrication of the prototype, and testing of the prototype hardware.

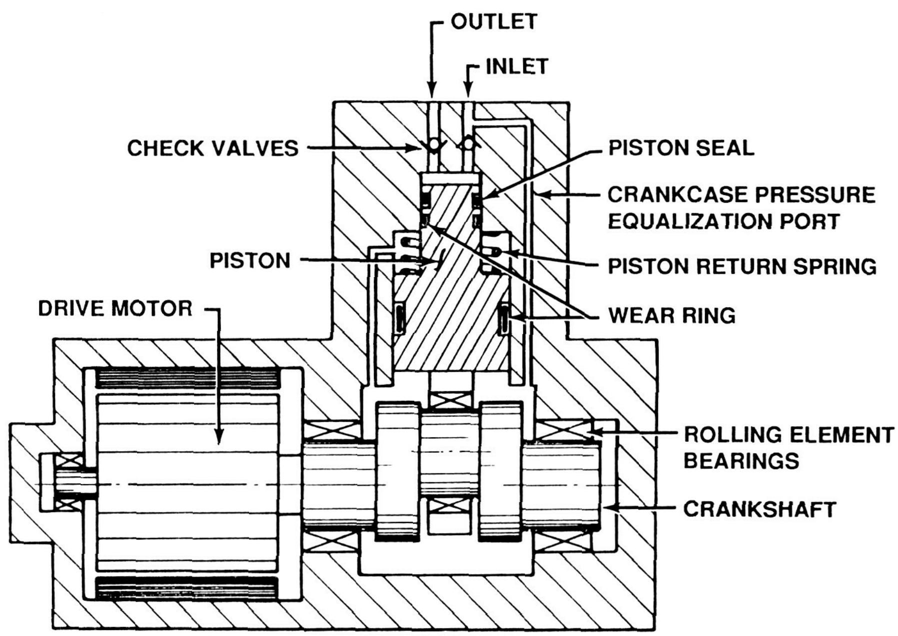
Southwest Research Institute (SwRI) has been awarded the contract to investigate the technology required for compressor development in support of the Space Station Program. The contract started on September 29, 1988, and will continue for 20 months.

SwRI has developed a preliminary concept for the general compressor design. The concept represents one stage of a four-stage reciprocating compressor with individually driven pistons. Each stage has an electric motor which is encased in the suction side-envelope. This envelope is maintained at the stage suction pressure to minimize bearing and seal loads. The piston is actuated by a bearing driven with an eccentric crankshaft. A spring provides the necessary force to return the piston and create the suction pressure.

SwRI has identified two critical design issues that must be addressed before the detailed design effort begins. The first relates to compressor cooling. The conceptual design requires small displacement stages to accommodate the low flowrates identified in the compressor application requirements. Cooling the cylinders will be necessary to maintain the gas temperatures below the maximum allowable limits during the compression cycle. A small engine with approximately the same swept volume as the conceptual design is being modified to study the heat loads generated in the cylinder. The engine modifications include adapting a water-cooling capability for the cylinders and attaching pressure and temperature transducers. Testing will begin soon after the modifications have been completed.

The second critical design issue relates to the check valves required by the compressor. Valve dynamics will impact the overall performance of the compressor and specificattention should be given to proper valve design. Therefore, the engine discussed above will be used to test compressor check valve designs. The heads of the engine will be modified to incorporate both reed and plate type check valves. The reed type potentially is the simplest and is used in other applications where the compressor must operate over wide speed ranges.

The contract schedule has been structured to provide support to the WP-02 prime contractor in a time frame consistent with the Space Station Preliminary Design Review (May 1990)./ The data generated by SwRI will be available to the prime contractor to support component selection for the Fluid Management System hardware. This contract will also generate compressor designs for use by the tanker resupply systems (satellite servicing) under study at JSC.



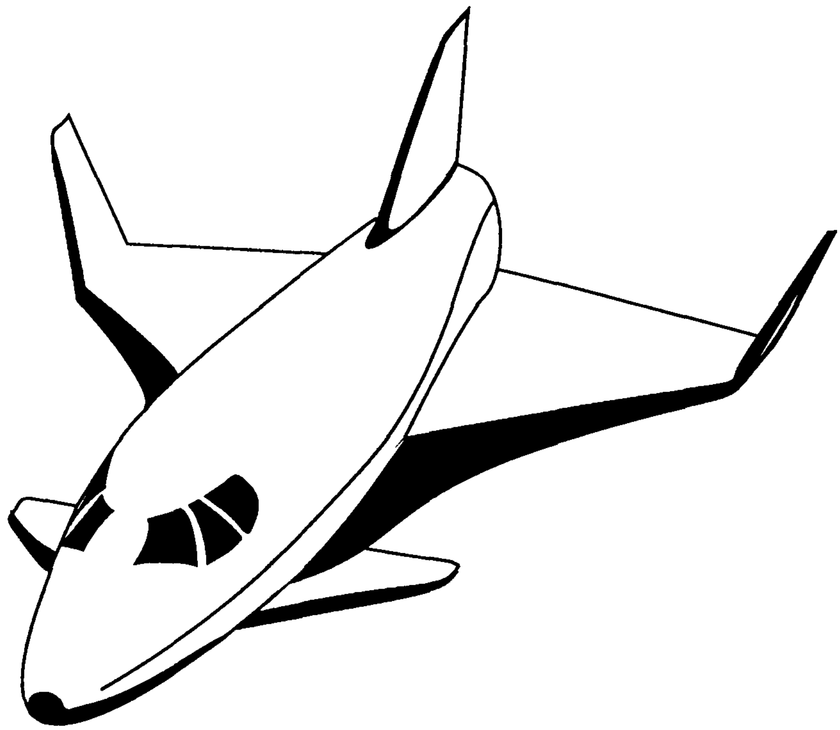

**Preliminary compressor concept.**

## A Conceptual Design of a Personnel Carrier Shuttle II

PI: Wayne L. Peterson/ED2
Kevin C. Templin
Reference STT 4

The objective of this study was to develop a conceptual design for a Personnel Carrier Shuttle II. The purpose of this shuttle vehicle would be to rotate Space Station Freedom crews. Design requirements called for the vehicle to be fully reusable, to return to Earth by landing on a runway, and to provide crew escape capability during all phases of ascent and descent. It was assumed that Space Station crew size would be limited to eight people and that two crewmembers were required to pilot the vehicle. This study was intended to address a winged vehicle concept. Previous NASA studies had already examined lifting body concepts and ballistic entry vehicles to rotate Space Station crews.

The study resulted in a conceptual design of a Shuttle II Personnel Carrier. Aerodynamic analysis confirmed that the concept could be trimmed hypersonically. The vehicle utilized a canard and flap configuration for added lift during landing at lower angles of attack. Landing at an angle of attack of 8 degrees, with a flap deflection of 30 degrees, resulted in landing speeds of approximately 160 knots. The vehicle had a crew of two and a total passenger size of up to eight people. The vehicle was designed without a main propulsion system. Orbit insertion was accomplished with the use of an expendable launch vehicle. Crew escape was integrated into the design, using a rocket and parachute system capable of landing the entire orbiter if necessary. Gross vehicle weight was approximately 32,000 lb; inert vehicle weight was approximately 27,000 lb; and dry vehicle weight was approximately 21,500 lb.



Line drawing depicting proposed design of the personnel carrier Shuttle II.

## SCRAM - Conceptual Design Study

PI: George A. Zupp, Lead/ED2
Wayne L. Peterson
Chris J. Cerimele
Michael J. Stagnaro
Brian P. Ross
Reference STT 5

A study was conducted to define the characteristics of a simplified Crew Emergency Return Vehicle (CERV) that would return Space Station Freedom crew-members to Earth in the case of an emergency requiring immediate evacuation. The objective of the study was to design a vehicle with high reliability and low maintenance that incorporated simple, passive systems where appropriate. Mission time should be minimized, consistent with flight safety rules and procedures. This reduces the size, weight, and performance requirements of the subsystems. This also implies that large dispersions between the touch-down point and the desired target area are acceptable. Therefore, the vehicle must be a seaworthy craft, since the crew might have to wait for extended periods before being rescued. The design must also interface with both Space Station and the Space Shuttle, as well as limit the entry g-loading imposed by crew physiological constraints.

The Station Crew Return Alternative Module (SCRAM) was the result obtained from the mission requirements and the design philosophy used in the simplified CERV study. The vehicle utilizes a Viking shaped heat shield that is separate from the crew module, allowing water to fill the void between the shield and themodule, providing dynamic damping while buoyant.The Viking-shaped heat shield also provides good entry stability along with a fairly low ballistic coefficient which reduces the entry g-loading. The crew module is sized for six crewmembers and designed for a total mission duration of 3 hours. A passive ECLS consisting of wax for thermal control and bottled air for life support was baselined. Deorbit propulsion is provided by a hydrazine propulsion module that is jettisoned after the deorbit burn. A cold gas system is used for reaction control throughout all phases of flight. An Apollo-type parachute system was baselined for landing. The gross weight of the SCRAM with a crew of six at Space Station separation is 10,039 lb, and the vehicle's inert weight at splashdown is 9100 lb.

## Orbital Debris Studies

**PI: Donald Kessler/SN3**
**Reference STT 6**

During the past year, a significant change has been made in the orbital debris model, based on new data and new calculations. The new model predicts an environment in the 1-2 cm size range that is a factor of 2 - 10 times larger than previous predictions. This will have a significant effect on the Space Station Freedom design.

### New Orbital Debris Model

Past models assumed breakup conditions which did not produce a large number of small objects. This assumption produced numerous small debris objects that were consistent with interpretations of telescopic data which assumed a high albedo for debris fragments. However, our recent measurements to determine the albedo of orbiting debris has shown that this interpretation is wrong and that the albedo for debris is generally very low. The particles are darkened by exposure to solar radiation or by soot deposited in the breakup. As a consequence, the sizes of debris detected by telescopic measurements are larger than we had thought. In addition, our satellite breakup analysis has indicated that many of the breakups are likely to be in a class that is expected to produce small particles. In addition, we now have a much better understanding of the small debris population from material retrieved from the Solar Max satellite. These new interpretations and data have produced a new model for the debris environment, which predicts much larger debris population levels than before. The design environment derived from this model is shown in the illustration which also shows the old design environment (JSC20001). This environment is expected to be officially approved as part of the Space Station design reference environment early in CY89.

### New Space Station Awareness

There is now an increasing awareness of the problem in the Space Station organization:

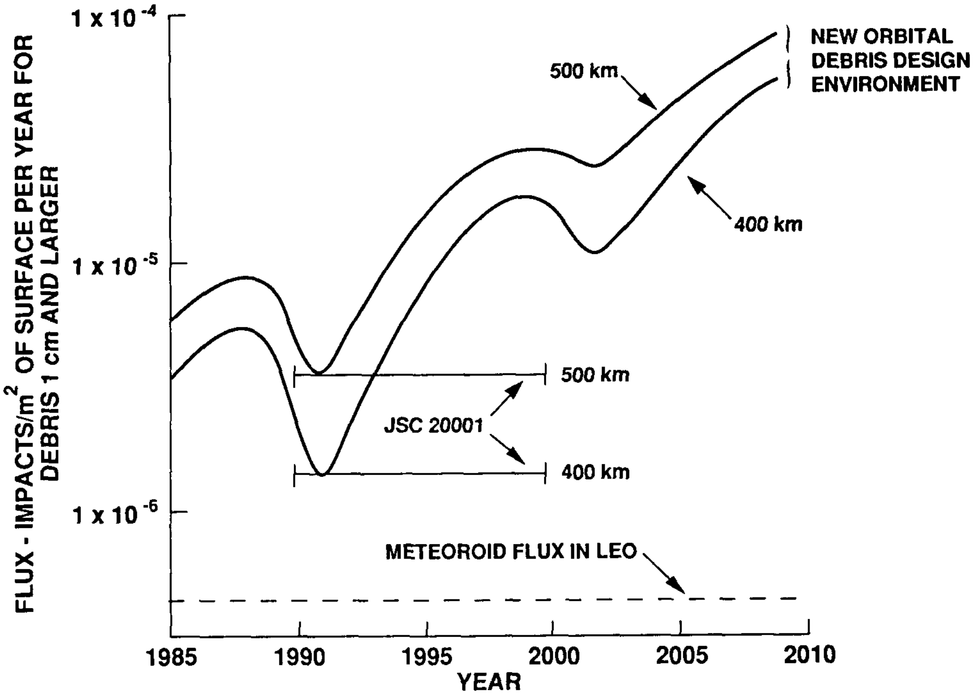
- McDonnell-Douglas is indicating a need for large shielding requirements for tanks and pressurized fuel lines.
- MSFC is reflecting an increased requirement for shielding of the pressurized volumes.
- The potential problems from secondary ejecta from an impact is getting attention from both JSC and MSFC.
- The problem of collision avoidance of the trackable debris population is beginning to be discussed.
- JSC is concerned about small particle impacts which remove protective layers designed to resist atomic oxygen erosion.

There are other critical problems yet to be addressed, such as power generation and distribution, EVA activities, etc.

### Model Verification and Debris Monitoring

In order to verify these model predictions in time for the Space Station CDR's, and to monitor the debris environment in the future, a Debris Environment Characterization Radar ( DECR) has been proposed to the Administrator by JPL and JSC. The radar is to be built by JPL, and turned over to DoD and JSC after it becomes operational at a near-equatorial site some time in 1992. The Administrator approved release of the RFP for the radar and the contract award by JPL are expected in July 1989. As a way of testing radar concepts for the DECR, JPL conducted a test using the Arecibo planetary radar system. This radar is theoretically capable of detecting a 0.6 cm object at 500 km. altitude. Results from this test are summarized in Table 1, where it is shown that JPL reported results from this test that agreed with our current model "within 20 percent" for objects down to 0.6 cm in diameter. However, we consider the model to be uncertain by a factor of 3, and because interpretation of their data is not straightforward, we are not yet ready to fully endorse their conclusion.

In addition, we are obtaining and analyzing optical data from the US Space Command telescopes at Maui and Diego Garcia. Using our recent data for debris albedos, the detection rate of debris from these telescopes agrees with the model predictions to within 50 percent.




Orbital debris design environment.

- OBSERVATION TIME - 21 HOURS (28 TAPES)
- DATA ANALYSIS IN PROGRESS
  - 28 TAPES PARTIALLY ANALYZED (d > 1 cm)
  - 6 TAPES FULLY ANALYZED (d > 5 mm)

PRELIMINARY MODEL COMPARISON

| EVENT SIZE | MAIN BEAM EVENTS PER DAY | |
|---|---|---|
| | ARECIBO RESULTS* | MODEL PREDICTION ** |
| 5 mm < d < 6 mm | 123 | 52 |
| 6 mm < d < 7 mm | ~11 | 29 |
| 7 mm < d < 8 mm | ~11 | 17 |
| 8 mm < d < 9 mm | 0 | 11 |
| 9 mm < d < 1.0 mm | ~5 | 8 |
| 1.0 mm < d < 1.5 mm | 0 | 16 |
| 1.5 mm < d < 2.0 mm | ~11 | 5 |

* BASED ON 6 FULLY ANALYZED TAPES

**ALTITUDE LESS THAN 1000 km

Orbital debris radar - Arecibo data summary.

## Orbital Debris Control

**PI: Andrew J. Petro/ED2**
**Reference STT 7**

Manmade debris in Earth orbit represents a collision hazard to valuable satellites and manned spacecraft. Particles which are too small to continuously track can collide with spacecraft at high velocities and cause catastrophic damage. Collisions among large objects in space are rare. Collisions among small debris particles are more common and are the source of a growing debris population.

Currently, there are no measures taken to control the growth of the debris population. This study was conducted to identify potential control techniques. In the study, three general approaches were investigated: 1) actively retrieve large objects, 2) include provisions for disposal in new spacecraft designs, and 3) deploy a sweeper device to remove small debris.

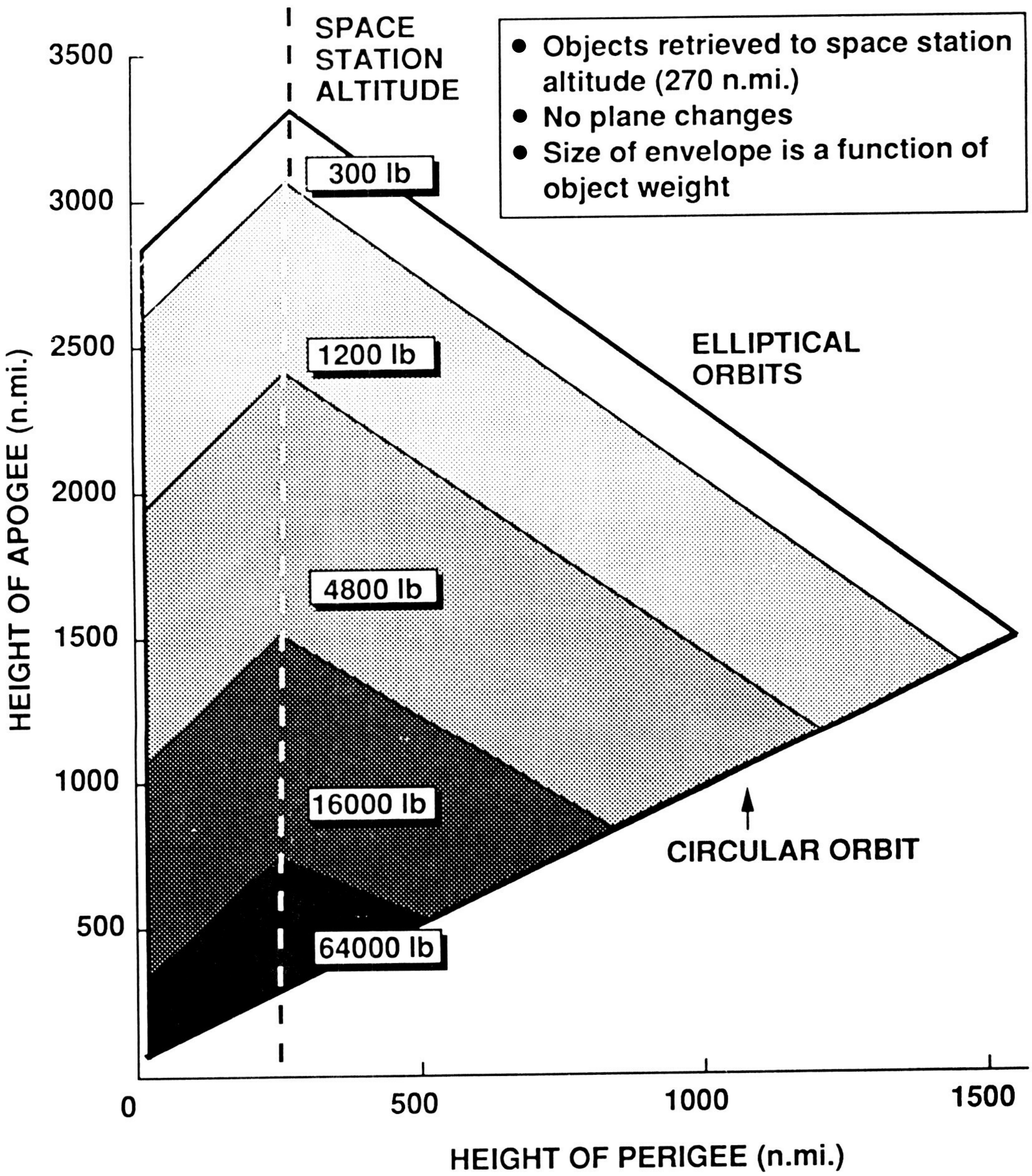
For the retrieval option, the proposed orbital maneuvering vehicle was evaluated as a means to capture inoperative satellites and other large objects. The captured objects would be collected at a particular location in Earth orbit or released on a trajectory which would result in atmospheric entry. The retrieval range of the orbital maneuvering vehicle is shown.

Propulsive deorbit packages and drag augmentation devices, such as a large balloon, were considered as disposal provisions for spacecraft. The disposal device would be part of the original spacecraft equipment and would be activated when the satellite or rocket stage completes its mission. The balloon device is simple, inexpensive, and reliable, but analysis indicates that it will only function below an altitude of approximately 700 kilometers. The propulsive device is more complex, but it is practical for spacecraft at any altitude, including rocket stages in geosynchronous transfer orbits.

One concept for the sweeping of small debris, proposed by Donald Kessler of the Johnson Space Center, is to place large foam-filled balloons in Earth orbit. These balloons might have diameters of a mile or more. Small debris would randomly impact the balloon and either become embedded in it or decelerate enough to cause a rapid decay from orbit. However, a passive debris sweeper cannot avoid collisions with functional satellites or with objects which are large enough to destroy the sweeper. Providing collision avoidance with an active control and propusion system for a huge balloon is impractical.

As part of the study, a concept was developed for solving the collision avoidance problem for debris sweepers. Instead of having a spherical shape, the sweeper material is deployed in large panels, like the vanes of a windmill. The panels rotate continuously around a core spacecraft. The core contains tracking apparatus which monitors objects that are on a collision course with the sweeper. The rotation rate of the sweeper is controlled to selectively avoid or collide with objects.

It was a conclusion of the study that, in comparison with removal of large objects, removal of small debris will be an extreme technical challenge and may be economically impractical. Since small debris is produced by collisions of large objects, removing large objects is an effective method of reducing the general debris hazard. The best technique for controlling the population of large debris is to include disposal provisions in the original design of all new spacecraft, including rocket stages. In other words, prevention is the best cure for the orbital debris problem.




Range of objects accessible with OMV.

C-2

## Robotic Vision/Tracking Sensors

**PI: D. E. Rhoades/EE6**
**Reference STT 8**

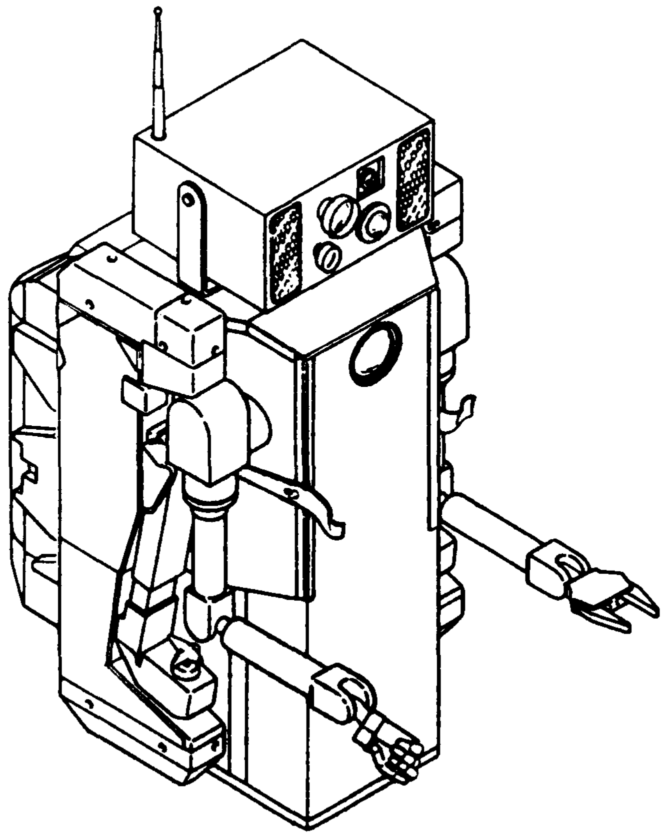
Efforts are continuing at JSC to develop vision systems and/or tracking sensors to accurately identify targets or target features and to determine their positions and attitudes. Candidate techniques being studied and evaluated include three-dimensional lidar, video imaging processing, millimeter-wave radar, optical tone ranging, and infrared sensors.

One project that implements a combination of sensors is the Extravehicular Activity Retriever (EVAR). This is a three-year/three-phase ground demonstration of a concept that will result in a robotic system concept to retrieve loose objects in space, from a dropped tool to a disabled astronaut. The system consists of a Manned Maneuvering Unit with a robot body attached, including two robotic arms. A target recognition/tracking system, using a video camera as its sensor, provides the capabilities to pick out simple shapes from a scene by using voice commands, lock on and track the specified object, and give position information for rendezvous. A three-dimensional imaging lidar (Three-Dimensional Mapper) mounted on the top of the EVAR provides range information concerning targets and any obstacles that might be in the robot's path. The phase I demonstration was performed on the JSC Precision Air Bearing Table in April.

Another application of the video tracking system is to provide guidance information for the Shuttle Remote Manipulator System (RMS). This will aid the operator in achieving a more efficient rendezvous with a payload. A demonstration of this technique was performed at the JSC Manipulator Development Facility in July 1988.

After manually acquiring a target in the payload bay, the video tracking system autonomously sent position commands to the RMS computer to guide the end effector down to the target.

Many improvements are being made to increase the usefulness of and to expand the applications of the existing hardware.



**Extravehicular activity retriever.**

## Superfluid Helium Tanker

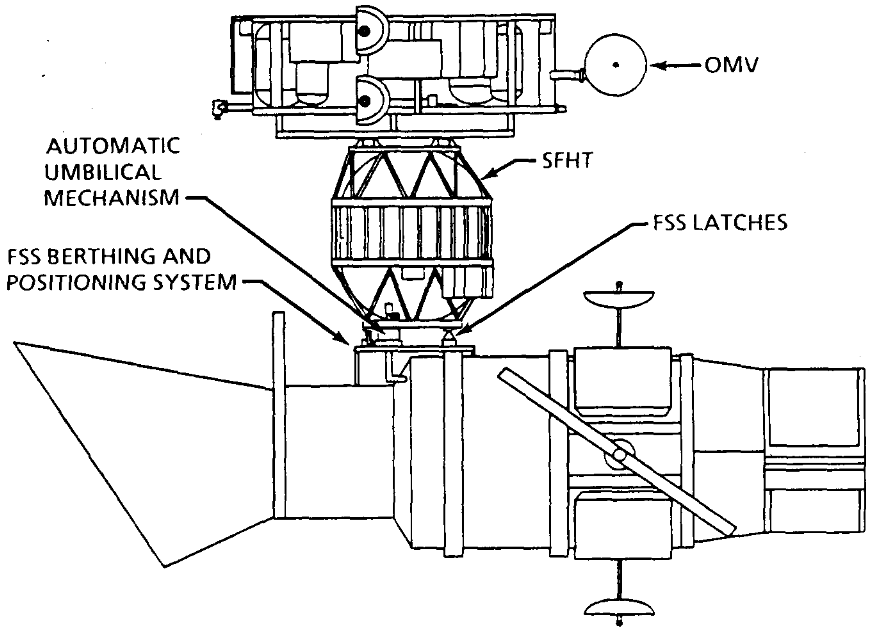
**PI: William C. Boyd/EP4**
**Reference STT 9**

Studies of the on-orbit refueling market reveal the need for superfluid helium (SFHe) resupply in the 1998 time frame. SFHe, or Helium II, finds its use in applications where a temperature below 2 degrees Kelvin must be achieved and where its unusual properties are of benefit. One application of SFHe is the cooling of detectors and other electronic sensors. The low temperature reduces thermal noise and provides a constant temperature environment for the sensor. In devices using superconduction to achieve high magnetic fields, SFHe is used for its heat transfer characteristics. Examples of such devices are semiconducting particle detectors and large-scale infrared detectors for astrophysical studies. The Infrared Radio Astronomy Space telescope (IRAS) and the Infrared Telescope (IRT), flown on Spacelab 2, both used SFH3. Numerous future spacecraft will require superfluid helium resupply, including Space Station Freedom modules, space station attached payloads such as the Particle Astrophysics Magnetic Facility (ASTROMAG), the Advanced X-ray Astrophysics Facility (AXAF), and the Space Infrared Telescope Facility (SIRTF). Resupply of superfluid helium will enable these complex and costly scientific satellites to remain operational for longer time periods.

The Johnson Space Center is responsible for the definition and development of orbital resupply tankers. System studies and prototype hardware development activities have been performed to determine the best approaches to be taken for the resupply of numerous fluids and gases. The unique characteristics of SFHe result in the need for radically different approaches to the design of certain subsystems for space transfer of this fluid. Management of the heat leak for storage of SFHe is critical because of the small amount of heat required to degrade the fluid from its superfluid state at or below 2.17 degrees Kelvin to its normal, or helium I, state above 2.17 degrees Kelvin. Below 2.17 degrees Kelvin, helium possesses characteristics exhibited by no other fluid, the most striking of which is that it can flow through capillaries so rapidly that it appears to have zero viscosity. Devices consisting primarily of porous material utilize this effect for pumping, venting, and heat removal from the storage vessel.

Another unique property of SFHe is its extremely high thermal conductivity. Experiments have shown that SFHe has a conductivity significantly higher than that of copper at room temperature. This property assures that the liquid in the storage vessel will be at a constant temperature. In a zero gravity storage environment, this drives all the liquid to be in balance with the tank pressure, thus complicating tank pressure management.

The objective of this effort was to develop conceptual designs of a Superfluid Helium Tanker (SFHT) which will provide a means for resupply of SFHe to a variety of users from the Space Shuttle Orbiter, Space Station Freedom, and the Orbital Maneuvering Vehicle (OMV). Because of their large superfluid helium requirement, ASTROMAG and SIRTF are presently the design drivers for the SFHT. Three parallel twelve month design studies were completed in FY88. Designs of SFHT fluid, structure, thermal control and avionics systems were developed. Tanker capacity ranged from 6,000 liters to 10,000 liters. Interfaces with several launch vehicles, including Space Shuttle, Delta, and Titan, were identified, as were those with OMV and Space Station. Analyses confirm a nine-month on-orbit hold capability at Space Station Freedom for long-term resupply requirements. Ground support equipment and operations were defined, and a market survey was conducted. SFHT weight, cost, and schedule estimates were also developed.




**In situ automatic SFHE resupply of SIRTF.**

## Superfluid Helium Orbital Resupply Coupling

**PI: William C. Boyd/EP4**
**Reference STT 10**

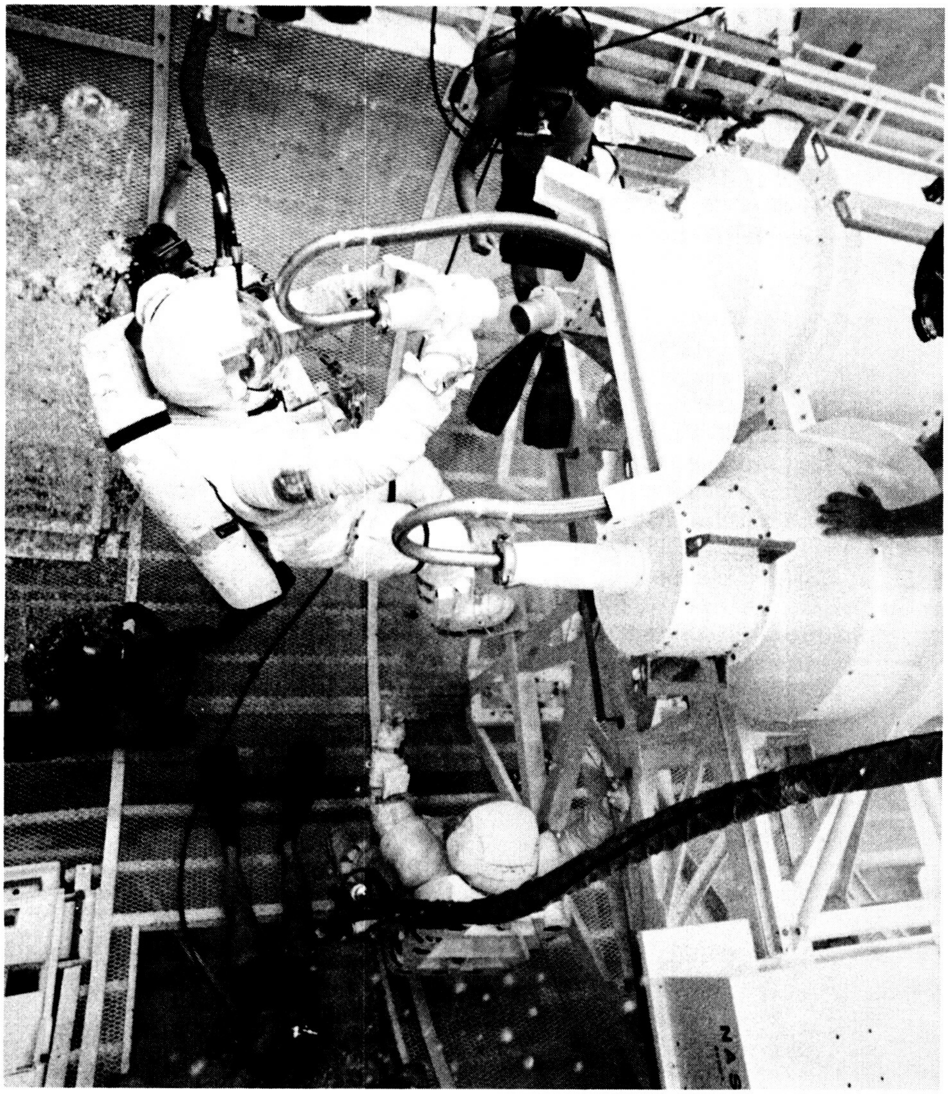
Orbital consumables replenishment provides an attractive method of extending the useful life of today's costly and complex satellites and is a key part of the economical and practical commercial development of space. An important element which enables this replenishment capability is a coupling (quick disconnect) between a supply tanker and the receiving spacecraft to allow fluid transfer. The Johnson Space Center (JSC) is responsible for the development and application of orbital resupply technologies for both Earth storable and cryogenic applications. Work is currently being done at JSC on the development of Earth storable tankers and superfluid helium tankers.

The objectives of this effort is to develop a coupling for the transfer of superfluid helium (He II) during the Superfluid Helium On-Orbit Transfer (SHOOT) flight experiment. This flight experiment is being managed by the Goddard Space Flight Center (GSFC) and is designed to simulate a satellite reservicing operation. JSC is responsible for the fluid coupling development as well as for coordinating the EVA activities for this flight experiment. Situated in the Space Shuttle payload bay, the experiment will consist of several fluid transfers between the two helium dewars and a period of extravehicular activity (EVA) by a crewmember to disengage and re-engage the coupling, followed by subsequent fluid transfer. During this experiment, the coupling will be evaluated for its thermal, fluid flow, and functional EVA performances.

This coupling may be subsequently incorporated into He II flight systems such as the Superfluid Helium Tanker (SFHT), the Space Infrared Telescope Facility (SIRTF), and the Particle Astrophysics Magnet Facility (ASTROMAG). The coupling incorporates the necessary redundancy features to comply with safety requirements for performing resupply operations in the Orbiter payload bay and at other on-orbit locations, as well as being readily modifiable for automatic operation. Contracts have been awarded to Moog Space Products for coupling development and to Ball Aerospace for cryogenic certification testing.

The coupling is designed to minimize heat leak (under 1.0 watt) in order to maximize the amount of fluid transferred. Due to the supercryogenic nature of He II (temperatures below 2 degrees Kelvin), the coupling must isolate the cold inner portions from the ambient outer portions. During FY88 a preliminary coupling design was developed, and subassembly development tests were performed on critical coupling components such as seals and thermal isolation jackets. A number of tests were performed in the Weightless Environment Training Facility (WETF) at JSC to aid in the coupling design from an EVA standpoint, as well as to investigate possible EVA scenarios.

The first flight hardware unit is scheduled to be delivered to GSFC in March 1990.



**Weightless environment training facility tests of Helium II coupling.**

## Satellite Services System

**TM: Charles T. Woolley/IB**
**Reference STT 11**

Section 118 of the NASA Authorization Act of 1988 (H.R. 2782) stipulates that "...the capital investment in space satellites and vehicles should be enhanced and protected by establishing a system of servicing, rehabilitation, and repair capabilities in orbit (hereinafter referred to as 'satellite servicing')." Encouraged by this directive, NASA is in the process of establishing National and Agency goals and objectives for developing and utilizing satellite servicing capabilities. In order to meet these goals, the fully operational Space Transportation System must meet requirements for a wide range of satellite servicing functions, including capability for payload deployment and retrieval, payload support on sortie missions, and satellite support servicing within or adjacent to the Space Shuttle cargo bay. Potential satellite support requirements include: (1) resupply of expendable items, such as propellants or raw materials for processing; (2) checkout, maintenance, and repair; (3) reconfiguration of payloads; and (4) orbital replacement unit exchange.

Previous studies defined the requirements and provided conceptual designs of various equipment. Some of this equipment is now available or under development, and the remainder consists of newly identified items for future development consideration.

The envisioned servicing equipment will be capable of multiple users on the Space Shuttle, Space Station Freedom, and the Orbital Maneuvering Vehicle and will provide services for satellites of wide-ranging varieties and orbital locations. This commonality will be achieved by maintaining standard interfaces, which are being developed in conjunction with the definition and development of the servicing equipment. Based on the customer inputs through study contracts and workshops, concepts are defined and given test bed evaluations leading to flight hardware specifications.

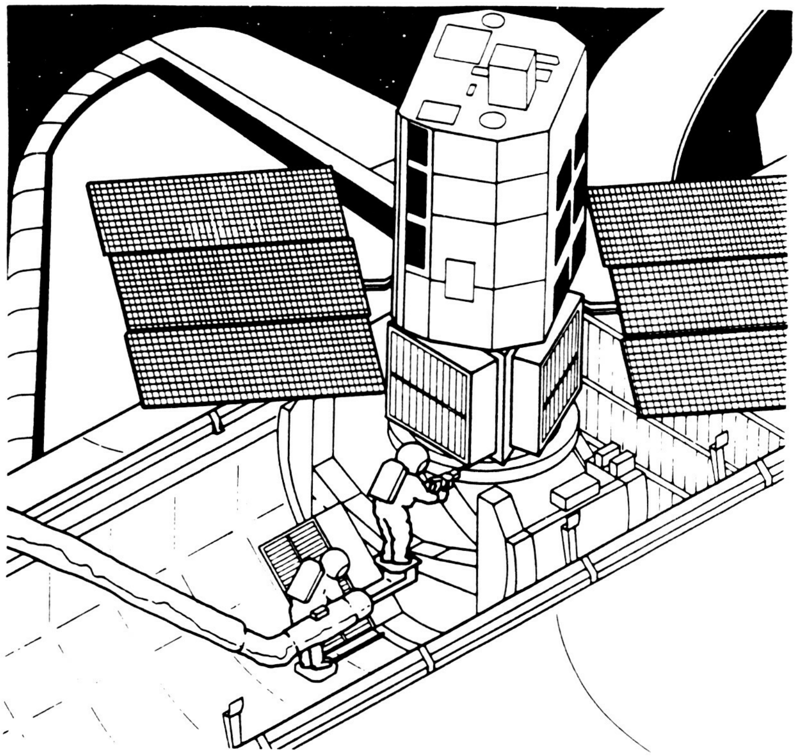
The NASA goals are to baseline generic servicing equipment and to standardize the servicing interfaces, thus allowing satellite developers to consider servicing in their original design phase.

Major activities conducted in 1988 include meetings and publications of the Satellite Services Working Group (SSWG) that provide the satellite designers and satellite users a forum and information to establish the requirements and conduct studies for the development of serviceable satellites.

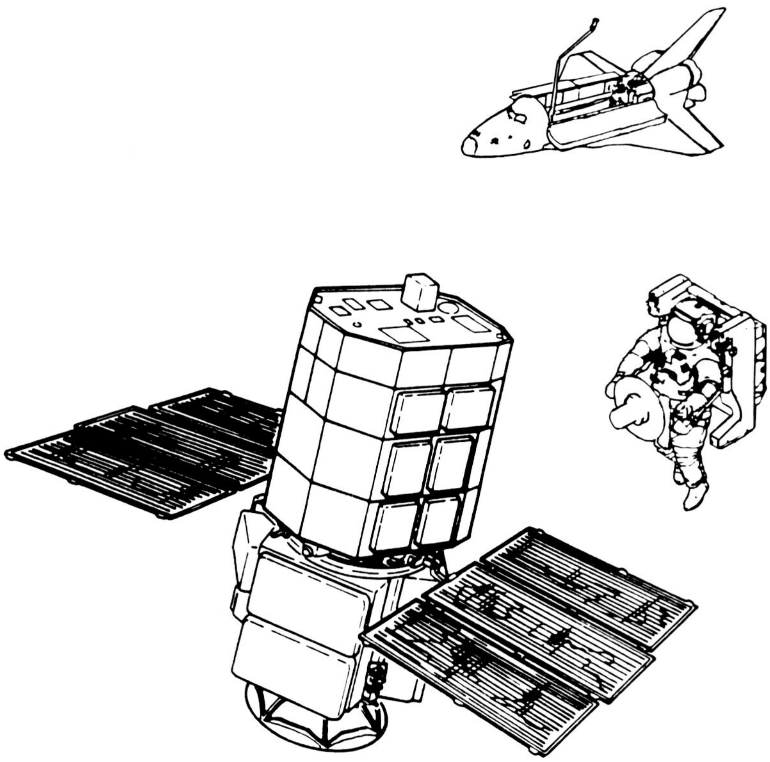
The objective of the SSWG is to coordinate, focus, and promote satellite servicing through meetings consisting of NASA, DOD, industry, academia, and international participants. The SSWG held nine meetings in 1988 and published the following document: *Technology Assessment For A Robotic Satellite Servicer System*, Volumes I & II (May); *Servicing Equipment Catalog (June);* a *Guide For Evaluating Costs Associated With Satellite Servicing* (June); and *Technology Assessment For A Robotic Satellite Servicer System*, Volume III & IV (July). In addition, work has begun of the following documents that will be published in 1989: Revision of *EVA Catalog, Tools and Equipment; Interface Design Requirements For Serviceable Satellites; Interface Design Requirements For Satellite Servicers; and, Satellite Servicing Standardization of Robotic Equipment.*

The *Servicing Equipment Catalog*, published in June of 1988, groups the equipment items into three categories: STS Flight Qualified, Prototype, and Concepts. This provides the satellite designers information as to the following:

- Which equipment items have already been developed and qualified, such as the Remote Manipulator System, Standard End Effector, and Module Servicing Tool
- Which equipment items have a working prototype, such as the Laser Docking System, Magnetic End Effector, and Power Ratchet Tool
- Which equipment items are still in the conceptual stage, such as the Satellite Workshop, Orbital Maneuvering Vehicle, and Orbital Maneuvering Spacecraft Consumables Resupply System



Servicing a satellite in the Shuttle payload bay.



EVA repair of a satellite.

## Lunar and Mars Exploration Studies

**TM: Mark Craig/IZ**
**Reference STT 12**

The Office of Exploration (OEXP) was established in June 1987 to provide recommendations and viable alternatives for an early 1990's national decision on a focused program of human exploration of the solar system, particularly of the Moon and Mars. The OEXP is also responsible for steering Agency investments on a practical, year-by-year basis toward providing feasible, defined choices in the early 1990's. With management centralized at NASA Headquarters, the OEXP leads a NASA-wide team consisting of all major program offices and field center organizations that are specifically dedicated to this effort.

To accomplish OEXP objectives, a study process was developed that begins with the yearly articulation by OEXP of guidelines and ground rules for human exploration studies. This activity serves to define a framework of initial concepts within which alternative strategies can be formulated and explored. The methodology used for implementing various strategic approaches, such as expeditions, science outposts, and evolution, is to identify reference missions to be examined as "case studies".

Once case studies have been identified by the OEXP, the Mission Analysis and System Engineering (MASE) function at JSC coordinates development of detailed case study descriptions and study initialization requirements and data.

Study progress for each case study is reported at periodic program reviews. These reviews generally include all study agents and support center representatives and often include representatives from each of the NASA Headquarters codes whose program support would be required in the execution of one or more of the case studies. Each of the affected NASA program offices submits hypothetical case study implementation plans which include analyses of each case study's effect on the office's strategic program plans and schedules.

The yearly outcome of this Agency-wide team effort is an annual report which progressively matures in its degree of technical and programmatic legitimacy. This report serves to document specific conclusions about the year's study efforts and provides valuable source material for planning subsequent study year activities.

In conjunction with case study definition and development of exploration cases, a parallel effort is to consider what these missions mean in terms of advancing scientific knowledge. The work performed in FY88 has been too preliminary to constitute a science strategy but has looked to incorporate some ideas on scientific objectives into the engineering analysis. In the future, the scientific rationale for human exploration missions will be more comprehensively developed.

A "case study" approach has been developed and used with the intention not of selecting one case in preference to the others but, rather, of isolating and identifying potential requirements and sensitivities that influence case study complexity, feasibility, and benefits.

Four case studies were developed during FY88: (1) Human Expedition to Phobos, (2) Human Expeditions of Mars, (3) Lunar Observatory and (4) Lunar Outpost to Early Mars Evolution. Selected to encompass a broad spectrum of objectives, capabilities and requirements, these cases also cover a variety of potential destinations, emphases on explorations, crew size and activities on planetary surfaces.

In the course of the detailed definition and assessment of the case studies, many insights have developed through a "case study" process. The purpose behind developing reference case studies is to define a set of strategies that been gained, regarding both specific case studies and human exploration missions in general. These topics, as well as other results of the FY88 study activity, are summarized in this volume.

### Exploration Case Studies

Exploration strategies are respond to different objectives or mode of implementation, so that a reasonable range of options can be understood. The number of potential case studies is very large, but only a few can be studied in depth. Additional cases can be constructed by rearranging elements or by extending the reference cases through trade studies that examine the effects of varying assumptions.

The case study process is iterative in nature among and within three distinct phases. The first phase addresses conceptual mission and system architectures. As part of this effort, mission and system requirements are defined to meet the exploration goals and objectives and user requirements. The mission and system requirements specify functional and performance parameters for elements defined by this study, identify environments in which elements must operate, and identify element design and operational constraints.

The second phase of the case study process addresses conceptual elements definitions, which are responsive to the mission and system concepts developed in phase one. Three areas were determined to be significant case study elements: space transportation systems, orbital nodes, and planetary surface systems. All are, in general, programmatically independent and can be functionally independent. The conceptual definition of these elements includes scaling data to support the synthesis in the next phase.

The third phase is a synthesis of the element concepts back into an integrated mission and system. The results establish a preliminary system concept and a reference configuration that is used to refine the study through several iterations. Where unique science and/or technology needs were identified, such as the possible implementation of nuclear spacecraft propulsion, special studies or assessments were made to identify strategies to accommodate those needs. A complementary set of broad trade studies, which are not case study specific, but which identify and assess key sensitivities, is run in parallel with these three phases, the refined case studies, associated requirements, and determined benefits become the knowledge base of exploration pathway sensitivities, which in turn is used to define the exploration initiative options, benefits, and risks.

**Conclusions and Opportunities**

As a result of this process of developing a broad spectrum of strategies and approaches, a fairly extensive base of information has been developed that has enabled some new insights to be gained. One key finding from this year's studies is that the strategies and approaches employed in some case studies were good choices, and in other case studies were bad choices. For example, for the Mars Expeditions, the choice of mission profile, transfer vehicle and surface habitat mass and volume, and propulsion system, etc., drove the mass in LEO requirement to values that are prohibitive. While the scenario employed for the Mars Expeditions turned out to be a bad choice, having that result to add to the base of information is important. The "lessons learned" over the past year will be applied, in a continuing process of study, to the redirection and definition of future work. future work.

## Lunar Base Systems Study

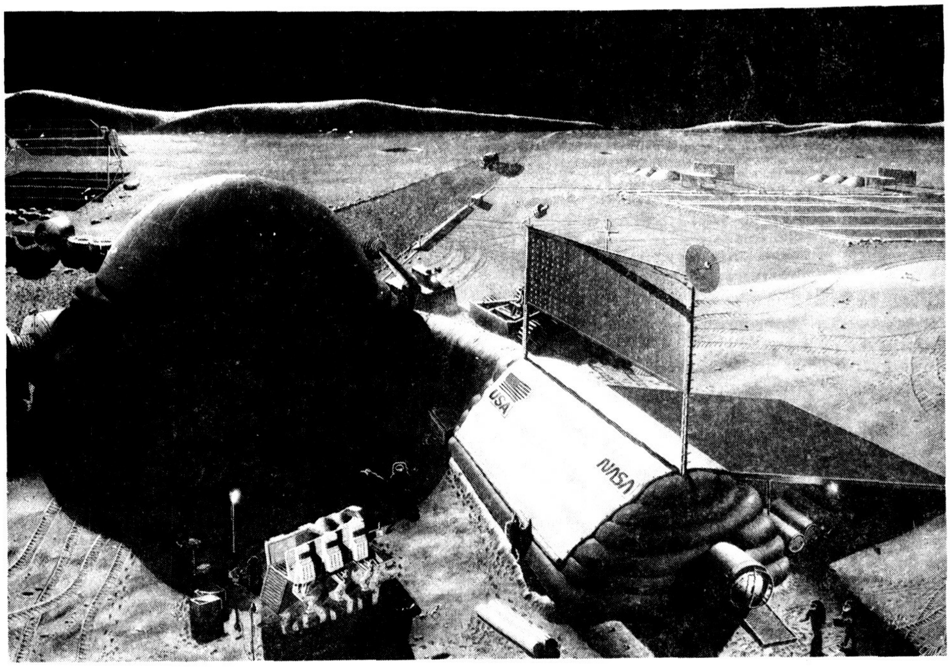
PI: John Alred/ED2
Reference STT 13

The Lunar Base Systems Study has been a joint effort by NASA and the contractor, Eagle Engineering, to design a lunar outpost and the associated Space Transportation System. The outpost is to be established in the year 2005, and is to support up to 12 people.

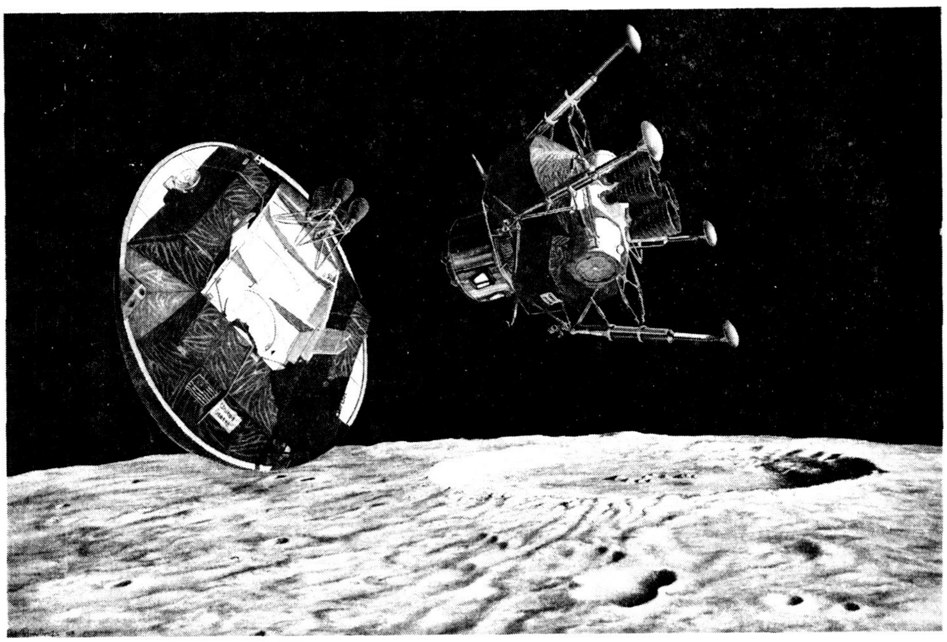
Through in-house design and contractor support, transportation elements such as a Transportation Node in low Earth orbit, an Orbital Transfer Vehicle to bring payloads to lunar orbit, and a Lunar Lander have been defined. Reference missions and operational scenarios for these vehicles have also been defined, as well as the Earth-to-orbit launch requirements to support them. A series of orbital trajectory programs with documentation were developed. These programs will be used in future lunar base studies.

The products of the study also included conceptual designs of surface systems. Surface transportation, landing facilities, construction equipment, power systems, and a lunar oxygen plan were designed. The contractor's contributions were integrated into NASA work defining the lunar habitation and lunar development timeline.

The result of the Lunar Base Systems Study is a broad, preliminary picture of a lunar outpost at the turn of the next century. By reviewing the results of the study, key technologies required for the lunar outpost can be identified for development. The study has also provided NASA with complete documentation and software tools to aid further study.




(1) The Lunar outpost.



(2) OTV and Lunar Lander.

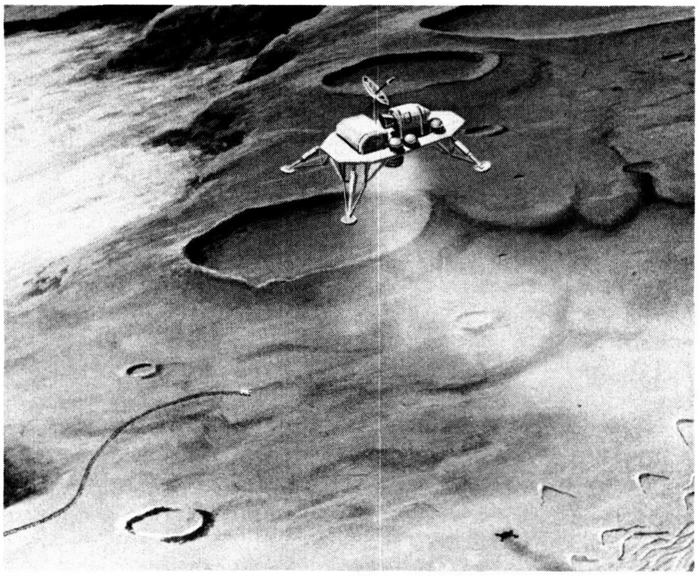
## Landing Analysis for Mars Sample Return Mission

**PI: Gene Mc Swain/EH2**
**Reference STT 14**

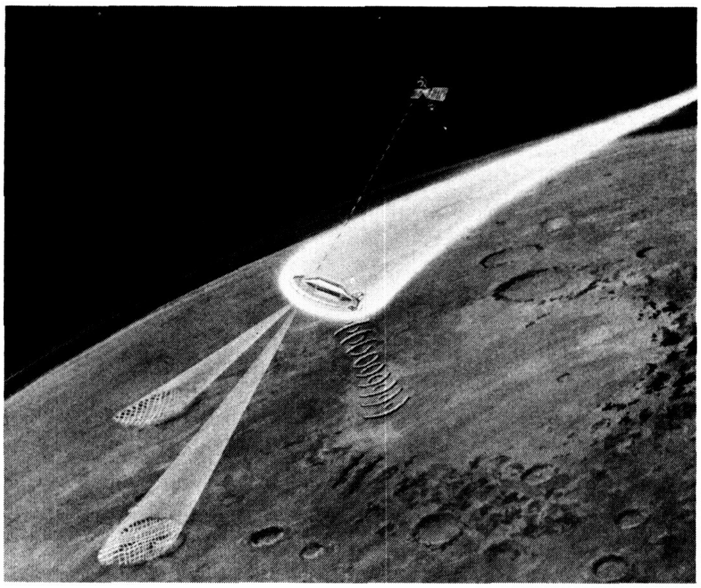
A key area of the Mars Rover Sample Return Mission (MRSR) is the landing of the rover and the ascent vehicles on the Martian surface. Although the Viking program successfully landed two probes on Mars, subsequent analysis of the size and distribution of rocks in the vicinity of the landers indicated that the probability of failure during landing was greater than originally estimated. For a sample return mission, a failure probability greater than 1 percent is unacceptable. The Viking landers were not steered to a specific target point on the surface. The MRSR landings must be near a site of interesting geology in order to maximize the scientific return. The probability of failure during landing can be reduced, and the requirement to land near an interesting site can be achieved by use of precision navigation techniques during the deorbit, entry and landing in combination with a hazard avoidance technique for the final phase of landing.

During FY88, the Johnson Space Center, in collaboration with the Jet Propulsion Laboratory, conducted a prephase A study to identify requirements and develop preliminary concepts for an MRSR mission. In support of this study, the Avionics Systems Division at JSC investigated guidance and navigation techniques that could make a precision landing on Mars possible. Study areas included: 1) optical navigation using sightings of the outer Martian moon Deimos during the Mars approach phase; 2) augmenting the inertial navigation system with landmark tracking and tracking of an orbiter vehicle during entry; 3) guidance and performance analysis for the chute and powered phase of landing; and 4) guidance interface requirements for a hazard avoidance system during the powered phase of landing.

Initial study results indicate that entry interface flight path errors for the aerocapture phase can be reduced to about 0.5 degrees (3 sigma) by using sightings on Deimos. This is significant since it implies that lift-to-drag ratio in the range if 0.5 to 1.0 for the aerocapture vehicle may be acceptable. For a landing from a 500 X 500 km orbit, a 4 km footprint landing zone can be achieved with a moderately accurate inertial measurement unit; the footprint can be reduced to about 1.0 km by tracking the orbiter during the descent. Chute performance studies indicate that a ballistic chute is adequate. A powered flight guidance system similar to that used for the Lunar excursion module landings on the moon was evaluated for the final phase of landing. Maneuverability during the powered phase was shown to be in the range of 1.5 to 3.0 km which is sufficient to compensate for knowledge errors that exist at that point concerning vehicle actual position and landing zone precise location. The conclusion then is that a pinpoint landing on Mars is possible.



**Powered descent of Mars descent vehicle for surface rendezvous with Mars rover.**



**Relative navigation techniques employed during Mars entry to reduce landing errors.**

## Mars Rover Sample Return Studies

**PI: H. A. Nitschke/EE6**
**Reference STT 15**

A series of parametric studies was conducted to determine the radar equipment requirements for on-orbit detection and tracking of the Mars Ascent Vehicle. The first parametric analysis briefly documented the radar parameters and tracking requirements of a KU-band system for ranging targets at a 500 km maximum distance. Transmitter power level for skin tracking and active target tracking were considered. Detailed system parameters for an orbital maneuvering vehicle (OMV) type of radar were calculated, including the transponder power requirements and the primary equipment power and system weight for Mars Orbiter operation. Additional calculations were completed for an advanced Mars orbital radar system based on projected 1990's microwave state-of-the-art technology.

The second report encompassed a system trade-off between radar transmitter power, primary equipment power, and system weight for a shortened tracking range of 250 km. Both passive and cooperative transponder-assisted tracking were considered.

In the third parametric analysis report, a series of computer plots was prepared to show the relationship between Mars Ascent Vehicle tracking range radar transmitter power, antenna beam width, primary system power, and radar equipment weight. Present and projected state-of-the-art microwave technology were considered for the Mars on-orbit rendezvous requirements. Based on the outcome of these studies, a recommendation was made to conduct parametric studies on the use of millimeter- wave radar technology in order to reduce antenna size, radar power, and equipment primary power requirements.

In a fourth analysis effort, a preliminary study was conducted on the sensor requirements for Mars on-orbit docking maneuvers, with the main thrust on laser docking systems. Preparation of the analysis report is near completion.

A fifth study started on the feasibility of a microstrip planar array antenna using an electronically steered beam for scanning the Mars topography of the landing site in which the Mars altimeter could be combined with a hazard-avoidance radar scanner. The preliminary study has shown the microstrip planar array antenna to have a number of advantages over a mechanically steered antenna such as:

- No mechanical moving parts (i.e., no mechanical servos are required)
- High-speed scanning of landing site
- Distributed electronically-steered beam which is advantageous for reliability, efficient radio frequency (RF) power delivery, and better receiver system sensitivity
- Lower weight of altimeter/hazard-avoidance scanner systems

## Intelligent Computer-Aided Training (ICAT)

**PI: Robert T. Savely/FM72**
**Reference STT 16**

This project has investigated the application of artificial intelligence technology to the development of autonomous intelligent training systems.

Training is a major effort at all NASA operational centers and has high direct and indirect costs. In addition, most critical training is obtained in an "on-the-job" setting. Such training depends on the ready availability of experienced personnel and is generally inefficient. Artificial intelligence (AI) approaches to training can

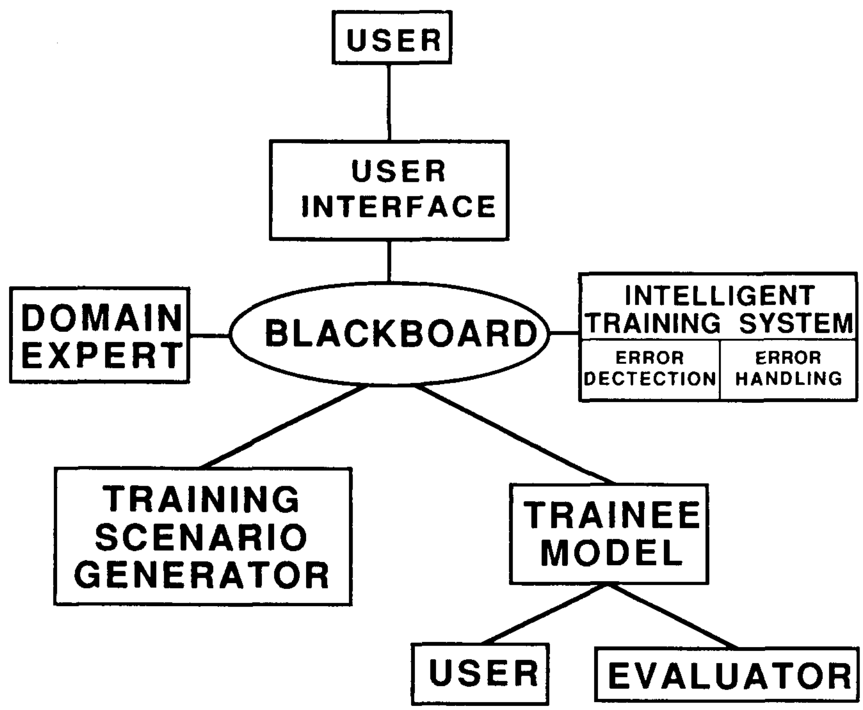
- Magnify the efforts of trainers to deliver training
- Capture perishable domain and training expertise
- Improve the maintainability of training systems
- Provide uniform and verifiable training, thereby enhancing safety and the probability of mission success
- Be delivered in a workstation environment and augment mainframe-based simulation training system

The first product of this research was an ICAT system for Space Shuttle flight controllers who guide the deployment of satellites. The Payload-assist module ICAT system (PD/ICAT) project was initiated in 1986, and development was complete in fiscal year 1988. The system has been used by both novice and experienced flight controllers at the Johnson Space Center. The figure shows the basic architecture of the system. It is characterized by four cooperating expert systems (a domain expert, a training system manager for both error detection and error handling, and a training scenario generator) that communicate via a common blackboard. Unique features of the system include

- Modularity to allow its adaptation to other training domains
- A flexible training approach that permits trainees to follow any correct path to a solution
- Detection of errors at the most appropriate level
- Diagnosis of conceptual or procedural errors and the provision of error responses tailored to the trainee's level of experience
- Creation of unique training scenarios based on the trainee's previous interaction with the system and the ultimate training objectives
- Generation of post-session reports for the trainee and historical summaries for the trainee's supervisor

The ultimate goal of this project is to develop a general-purpose software environment for the production of ICAT applications. Additional applications are being developed to demonstrate the applicability of ICAT systems in a variety of domains and to refine and extend the current architecture. These applications will serve as platforms for designing and developing a set of software tools for the production of ICAT systems for use by all NASA centers as well as other government agencies, the military, and the private sector.

The ICAT activity has been conducted jointly by the Johnson Space Center Mission Support Directorate Artificial Intelligence Section and the University of Houston-Downtown with support from Computer Sciences Corporation.




**Basic architecture of the intelligent computer-aided training (ICAT) system.**

## Advanced Software Development Workstation

**PI: Robert T. Savely/FM72**
**Reference STT 17**

The primary purpose of this project is to investigate knowledge-based techniques for software reuse. Software development is a serious bottleneck in the construction of complex systems. An increase of the reuse of software designs and components has been viewed as a way to relieve this bottleneck. One approach to achieving software reusability is through the development and use of software parts composition systems. Phase I of the Advanced Software Development Workstation (ASDW) Project began in the fall of 1985 and focused on the development of a knowledge-based software components composition system prototype. While the function and performance of the prototype were adequate, our experience in building this system prompted us in Phase II of the project to investigate ways to exploit the use of knowledge representation, retrieval, and acquisition techniques to reduce the amount of manual effort spent in the creation of similar systems. The resulting system can be viewed as a knowledge-based environment for the development of software components composition systems. Phase II began in the spring of 1987 and will conclude in February 1989.

During FY88, considerable progress was made in the development of the information retrieval system which uses a technique called specification-by-reformulation. This technique is based on a cognitive theory of retrieval from very-long-term memory in humans. Using specification-by-reformulation in a software parts composition system allows inheritance and constraint propagation feedback, application-specific access to domain objects and library package specifications, and specialization of specifications and code generation.

In addition to work on the information retrieval system, the ASDW project completed a formal demonstration in the spring of 1988, and underwent a major peer review.

## Integrated Autonomous Flight Operations Functional Simulation

**PI: C. J. Gott/FM72**
**Reference STT 18**

During 1988, we began developing a software test bed, AUTOPS (Autonomous Operations), to support systems analysis and to evaluate autonomous on-orbit operation during spaceflight. The test bed uses a variety of technologies and techniques to implement mission planning and monitoring functions, fault detection and recovery activities, sensor subsystem data processing, and guidance, navigation, and control functions. AUTOPS will support a wide variety of spacecraft and robotic manipulators. The activity supports the JSC Strategic Goals 3 and 4 to develop critical technologies for design and operation of space systems and to promote technical excellence.

The purpose of the effort is to create a software simulation environment that supports development of operations technology for automating on-orbit rendezvous and proximity operations, remote manipulation, and real-time support. The test bed is motivated by the need to provide mission requirements for autonomous activity during rendezvous operations for missions such as Mars Sample Return and satellite servicing. The test bed will evolve to include using hardware components to replace simulations as appropriate.

The test bed will permit evaluation of various control systems, including expert systems and fuzzy logic controllers, and their interactions with simulated vehicle components. The products of such evaluations are sets of rules, fuzzy set definitions, or procedural programs that would be incorporated into autonomous vehicle systems. Likewise, design of the sensor complement required to implement the control would be specifiable from test bed evaluations. A final goal of the test bed is to have real-time operation. This will allow a user to observe the effect of decision-making time on the quality of automation that can be obtained, to evaluate the interactions between coordinated or cooperating intelligent systems, and to determine any anomalous effects due to sensor sampling times or delays in system interactions with a simulated space environment.

We have completed an initial analysis of the test bed architecture requirements and have oriented that architecture to take full advantage of existing software and emerging standards. The test bed will use object-oriented programming to permit development of a library of vehicles to free the user of the test bed from the task of developing simulations for known vehicles with well-defined characteristics. The various control systems and simulations for vehicles will run as separate processes, communicating by a standard network protocol on a computer network. The use of parallel computation increases speed of execution, facilitates using existing simulation codes, and enhances fault tolerance through use of multiple processors and processor-independent codes. We plan an initial demonstration of concept in early CY1989 and to produce an initial operating capability for the test bed by the end of CY1989. A capable, fielded version is projected for the end of CY1990.

## Expert Systems Applications to Onboard Systems Management

**PI: Robert T. Savely/FM72**
**Reference STT 19**

Under a separate but related effort to the AUTOPS test bed project, in 1988 we have begun developing expert systems for diagnosing malfunctions and for planning and executing recovery from them in an electric power system and a propulsion system. These systems represent two of the numerous systems required to maintain space vehicle operation under autonomous control. After the capability is developed to do the diagnosis and recovery for each system individually, they will be combined to cooperate to assure that the recovery implemented is consistent with mission objectives, plans, and timing, as well as being a consistent and correct solution to the problem producing symptoms detected by the various trouble-shooting experts. The project supports the same JSC strategic goals as the AUTOPS project, namely to develop critical technologies for space operations and to assure technical excellence.

We have designed and implemented a prototype for a Shuttle-like electric power system called EPSYS. The prototype has already shown the need for coordination or cooperation in miniature. The diagnosing experts, built with the JSC-developed expert system tool, CLIPS, contain rules that detect faults and propose recovery procedures from limited perspectives for fuel cells, for electric power buses, and for the gas handling system that supplies hydrogen and oxygen gases to the fuel cells. For some faults, only one system proposes a recovery procedure. However, others cause several recommendations to be made that have to be resolved by a manager expert system that knows about relationships between the several diagnostic expert systems and that provides a consistent recovery action to be executed. This hierarchical arrangement could be extended for several layers to provide coordination for recovery from faults for the entire space vehicle. Other arrangements in which diagnosticians and/or managers cooperate to produce feasible solutions should be investigated.

In FY1989, we shall complete and demonstrate the EPSYS, the companion propulsion expert system, PROPSYS, and their combination into a coordinated system monitor. We shall begin the integration of these programs and concepts into the AUTOPS test bed.

## Autonomous Ascent Guidance Development

**PI: Dave Long/FM4**
**Reference STT 20**

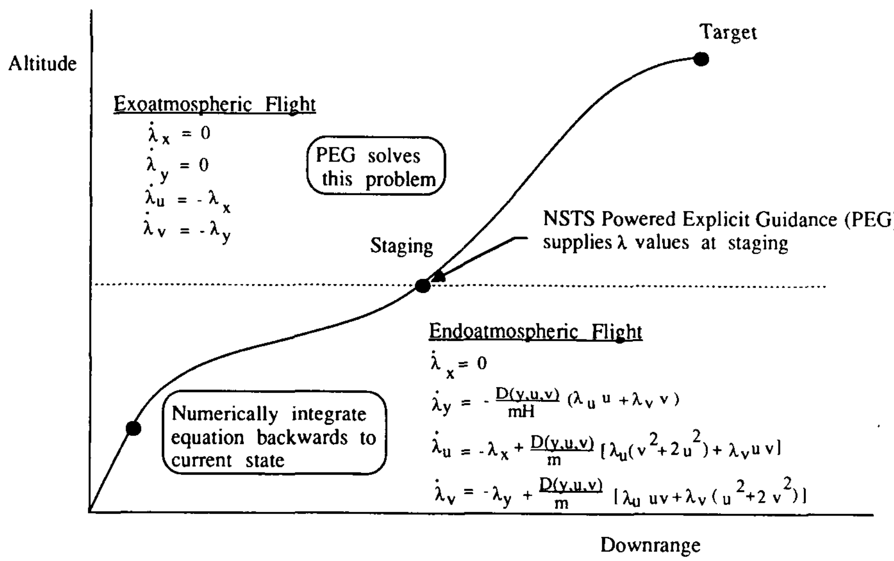
The primary focus in this task is to develop the requirements for a near fuel optimal ascent guidance system. The system will satisfy all launch vehicle attitude and trajectory constraints within an uncertain day-of-launch and systems performance environment. This system will result in reduced operations costs by eliminating many pre-flight activities and will increase safety and reliability by adapting to in-flight dispersions. The 1988 activities included investigating mission operations of the STS program, developing prototype guidance systems, and investigating new hardware requirements.

The results of the investigation of mission operations of the STS program have been published in a working paper titled "Launch Vehicle Mission Operations Technology Study." This paper reviews the decisions made during the design and development phase of the STS program that adversely affected mission operations. The generic functions of mission operations are defined, and mission operations goals for future launch vehicles are developed. Several technology studies are suggested, including developing an autonomous ascent guidance system.

Two prototype algorithms have been investigated as potential onboard guidance systems. The first algorithm is based on the linear quadratic optimization theory. This technique requires an optimal reference trajectory to be designed just before launch. The algorithm computes guidance controls that will meet all trajectory constraints while achieving the desired target conditions. The controls are chosen so the deviations from the reference trajectory are minimized. This technique performed adequately in engineering simulations; however, several drawbacks exist. The most severe drawback is that optimality is not ensured if the state deviates very far from the reference trajectory. Because of these draw backs, a second algorithm is being investigated.

The second algorithm is a hybrid optimization technique. The technique employs calculus of variations to determine the equations for the lagrange multipliers for atmospheric flight. These equations are integrated numerically during the endoatmospheric phase. The NSTS second stage powered explicit guidance (PEG) provides an analytic solution during the exoatmospheric phase. The hybrid technique employs an iterative scheme to compute the optimal guidance controls for the entire ascent trajectory as illustrated in the figure. Preliminary analysis indicates that this technique is viable; however, several issues remain unresolved.

Autonomous ascent guidance systems will impose new hardware requirements, including increased sensing capability and enhanced onboard computers. For example, the algorithms will require real-time knowledge of angle of attack and dynamic pressure to ensure that the trajectory constraints are not violated. As part of the algorithm development, the requirements for these sensors are being developed. These algorithms may require real-time numeric integration. This increased computational load will exceed the capability of current onboard computers. New computer technology such as parallel processors will be available for future vehicles, making numeric integration feasible.




**Hybrid optimization technique employs an iterative scheme to generate guidance controls.**

# Medical Sciences



## Summary

## Office of Space Sciences and Applications

**PI: Nancy Aldrich**

### Introduction

With NASA's return to manned space flight in October 1988, the Life Sciences Program at the Johnson Space Center (JSC) re-embarked on the quest for new and innovative technology with which to investigate human physiology before, during and after exposure to microgravity. An emphasis has developed since the publication of the last R&T Report regarding extended-duration crew stay time. This includes the Extended Duration Orbiter (EDO) project with crew remaining in orbit for periods of up to twenty-eight days and the Extended Duration Crew Operations (EDCO) project for Space Station Freedom with stay times of up to six months. Both of these programs will require operational capabilities for in-flight analysis. The technologies described in this report are in support of maintaining crew health and productivity, responding to medical emergencies, monitoring the internal environment, developing data bases, and assessing potential countermeasures.

In addition to these activities, there are additional technologies which have evolved including operational data bases, a human locator system, B-cell Hybridoma clones and the stability of ANF (Atrial Natriuretic Factor). The Biomedical Laboratories Branch at JSC has been involved in the latter two areas because NASA investigators have been concerned with fluid shifts and electrolyte balance during space flight since the Apollo era.

### STS Operational Medical Data Base

The Medical Operations Branch has developed an operations, medical data base. Operational consideration for manned space flight requires that flight crewmember medical information be readily available, accurate, and mobile. In 1988 a study was accomplished at JSC delineating the requirements for an operational medical data base and a program developed for Space Shuttle operations.

In addition to their obvious on-orbit duties, flight crewmembers travel extensively, and the flight surgeon must have access to medical data for pre-, in-, and postflight medical operations. In addition, medical data must be available for worldwide use in the event of a Transoceanic Abort Landing or Emergency Landing Site operation.

The Aeromedical data base has been developed using the Advanced Revelation relational program with modifications to provide data on flight crewmember position, spaceflight experience, active illnesses, inactive illnesses, allergies, medications, drug sensitivity test results and space motion sickness susceptibility. Additional capability for storage of flight-specific information has also been included. The data base employs a variable length field which permits more data to be stored than other programs. The program has also been designed for search capability in various clinical parameters. Modifications due to changes in medical requirements can be added easily without impacting existing fields. The aeromedical data may be stored on tape, floppy discs, laser cards or hard discs.

Due to mobility requirements, the program has been designed to operate on both the personal computers at JSC and the portable lap-top computers for flight surgeons traveling to launch and landing. In addition, if Rapid Response Team and Crew Recovery Team action is required due to a contingency landing, the lap-top computer is configured to function with multiple power sources throughout the world. This type of data base could be helpful for any applications in which rapid access to summary medical data is necessary in remotely deployed populations.

Although this technology was developed by the Systems Analysis Office of the JSC Engineering Directorate, it has potential medical applications.

### Locator System for Wandering Individuals

Space technology is being applied to the problems of memory loss in today's aging population as part of the NASA Applications Engineering Program. This project is being sponsored by the National Aeronautics and Space Administration, the Administration of Aging, the National Institute on Aging, the Veterans' Administration, and the National Institute on Disability and Rehabilitation Research. The mission of these federal agencies is to combine their expertise and resources to identify and support technology-based solutions to problems faced by the aging population. By working with Cortrex Electronics, Inc., the agencies are sponsoring the development of a notification and locator system to aid in the management of wandering behavior as exhibited by the mild to moderately cognitively impaired elderly.

The data collected during a needs-assessment study documented the problem of memory loss in the aging population. NASA and the four health agencies then chose to focus on the problem of wandering behavior and assigned the project to JSC, based on this Center's expertise in micro-electronics and communication and tracking systems. A competitive contract was awarded to Cortrex Electronics, Inc., and the design for the Locator System for Wandering Individuals has been completed. The system

prototype is currently being developed.

The system consists of an identification tag worn by the person to be monitored, a passageway detector, a perimeter detector, a portable caregiver unit for use in the home, a portable homing unit, and an institutional caregiver unit. The design phase included a literature search using NASA libraries and data bases, identification of design challenges, evaluations of existing products, and coordination meetings with the health agencies. The system concept which has been adopted has considered such factors as wireless communication link alternatives, radio frequency (RF) selection, Federal Communications Commission requirements, RF coupling between the transmitter or receiver and the human body, antenna radiation patterns, small antenna design analysis, and RF communication link analysis. The system is driven by the requirements for communication with multiple identification tags, reliability of communication, conservation of battery life, and identification tag location monitoring.

### Stability of Human Atrial Natriuretic Factor and Cyclic GMP in Plasma Samples

Human atrial natriuretic factor (ANF) is a potent compound secreted by the heart which has significant diuretic, natriuretic, and smooth muscle relaxant properties. The precise measurement of ANF levels in plasma samples is important in further elucidating the effect of this hormone on fluid and electrolyte homeostasis in humans. Recent studies have shown that cGMP can be used as a marker for ANF action. To ensure precise measurement of both ANF and cGMP in samples that must be stored before they can be assayed, an extensive study was conducted in the Biomedical Laboratories Branch to evaluate the stability of these compounds in plasma under various conditions of sample collection and storage.

Samples were collected with heparin or EDTA; they were stored cold, at room temperature or frozen; protease or enzyme inhibitors were or were not used. Radioimmunoassays (RIA) were performed to quantitate endogenous ANF and cGMP levels before and after sample storage. High performance liquid chromatography (HPLC) was employed to confirm RIA results and to determine if ANF or cGMP degraded during sample storage. Prior to performing the actual study, the laboratory conducted an extensive and systematic evaluation of the ANF and cGMP assay method placing particular emphasis on improving specificity. Using HPLC it was demonstrated that the major immunoreactive compound elutes at a position corresponding to that of ANF and cGMP. It was also shown that no interfering compounds were present in ANF-free and cGMP-free plasma after Sep-Pak C18 extraction and ethanol extraction, respectively.

The results of this study indicated that temperature is a critical factor in ANF stability. Endogenous and synthetic ANF are stable up to 4 hours in an ice bath in whole blood samples with or without the addition of an enzyme inhibitor. Degradation of spiked ANF occurred at room temperature in spite of the presence of the proteolytic inhibitor aprotinin (see illustration). On the contrary, it was found the cGMP is less sensitive to temperature. In EDTA plasma cGMP was unchanged for up to 24 hours at room temperature. Although the EDTA or heparinized plasma did not significantly affect ANF stability, EDTA does play an important role in cGMP stability. In heparinized plasma, cGMP was completely degraded within 4 hours. Therefore the data suggest that the use of EDTA is obligatory for cGMP stability in plasma samples not as an anticoagulant but as a preservative. The HPLC analyses utilized to verify the results of the stability studies are shown in Figure 2.

The finding of this study suggest that if plasma samples are to be used for ANF and cGMP quantitation, and the samples must be stored prior to assay, it is necessary to store EDTA plasma frozen. Because the inhibitors are not required, the plasma samples can be shared with other investigators for other hormone analyses.

### Presentation of Antigen to T Lymphocytes by Non-immune B-cell Hybridoma Clones

It is well established that B cells can serve as antigen- presenting cells (APCs) to T cells thereby eliciting an antigen-specific, MHC-restricted T cell proliferative response. B cell tumors, virus transformed cell lines, splenocytes fused with lymphoma cell lines, normal spleen and lymph node cells have all been used in different studies as APC's. Clearly, B cells do present different antigens, but no study has addressed the issue of specificity. It is understood that specificity exists at the T helper cell level. There is a question, however, of whether specificity exists at the initial stage of antigen interaction, i.e., does the APC have the capability to differentiate between antigens. Many investigators have imposed specificity on the B cell by targeting the antigens to the surface structures on the APC, but the question of specificity has not been studied with respect to non-immunized B cell APC function. As a result the JSC Biomedical Laboratories Branch performed a study in which B-cell hybrid clones, formed from cells with no predetermined specificity, are used to examine the ability of B cells to present two different antigens. Approximately half of the antigen-presenting cloned hybrids are general presenters and the other half are specific presenters.

The proliferative responses of HEL-specific and Mb-specific T cells were tested using irradiated B-cell hybrids as APC's. The B-cell hybrids which mediated T-cell proliferation were chosen and recloned by limiting dilution. The B-cell clones were then tested for their ability to present Mb and HEL to their respective specific T cell lines. Presentation by these B-cell hybrid clones was MHC restricted because they did not present Mb or HEL to non-syngeneic antigen-specific T-cell lines. Similarly, the T-cell lines do not accept antigens presented by non-syngeneic (H-2s) APC's.

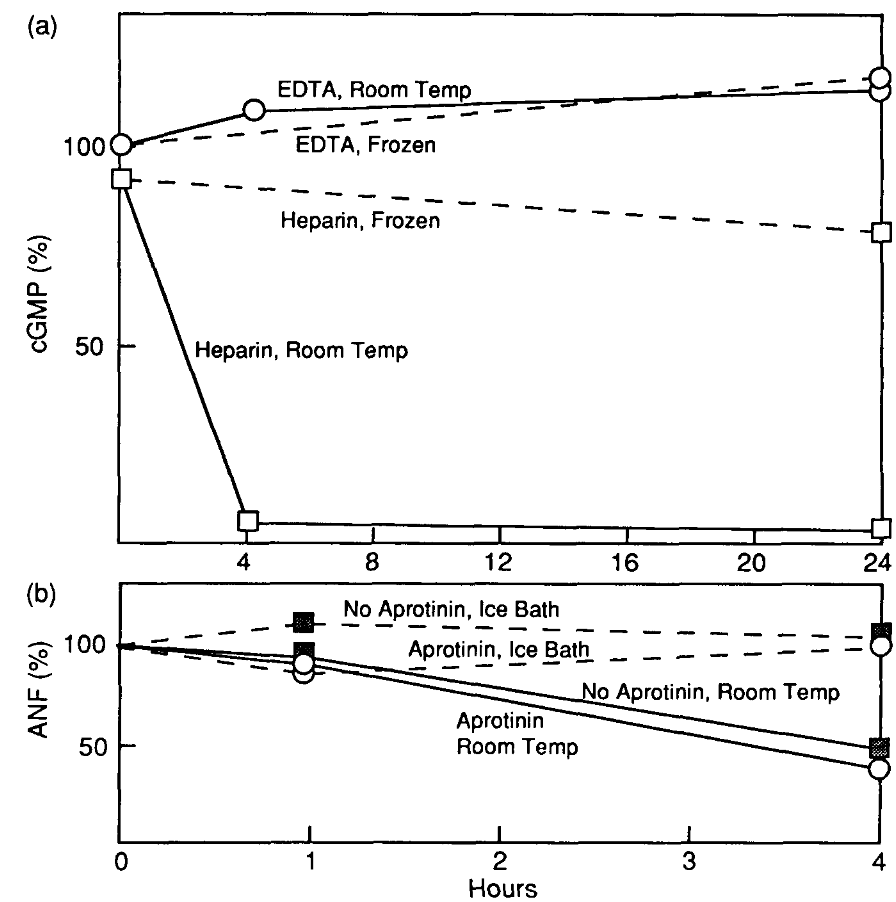
It should be noted that the non-secreting myeloma 653 was unable to present Mb or HEL to their respective antigen-specific T-cell lines throughout the dose range 1-200 ug/ml. Therefore, the presenting capability of the hybrid clones was an activity of the B cell and not of the myeloma cell. Others have hybridized B cell to a secreting antigen-presenting B-cell lymphoma, and therefore, the presenting capability of those hybrids came from the lymphoma and not from the naive B cell.

Previous studies have used antigen-specific T-cell hybridomas to study mechanisms of antigen presentation by B cells which requires accessory factors, i.e., IL-1. The system chosen for this study was both a complete system and less complex, enabling these experiments to focus directly on B cell antigen presentation to antigen-specific T cells.

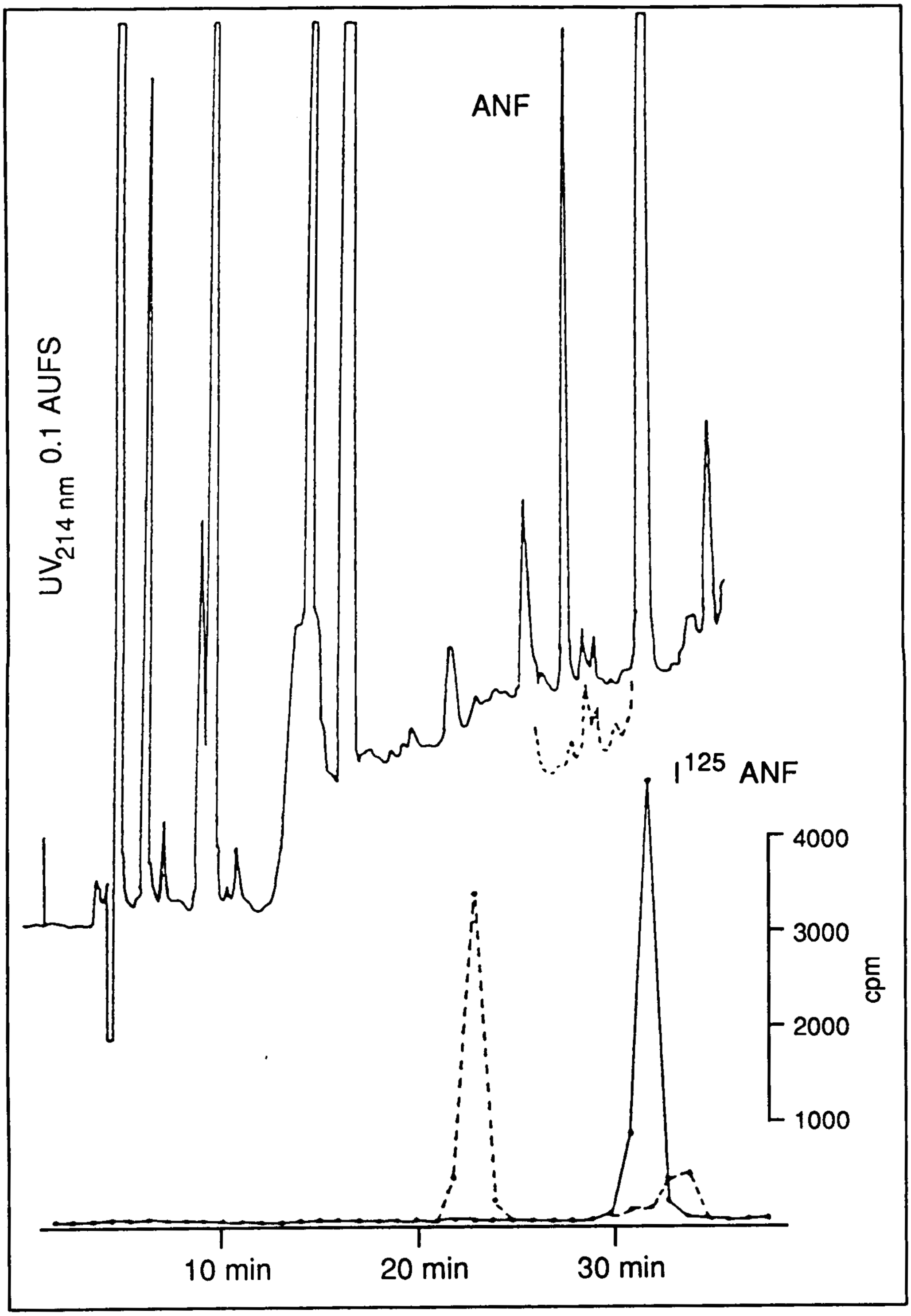
It has been suggested that APC can present an unlimited number of diverse antigens. Furthermore, previous studies have implied that general presentation occurs by the mechanism of non-specific fluid-phase pinocytosis, especially at high antigen doses, while specific presentation occurs at lower doses by receptor-mediated cell surface binding. However, it was recently reported that B-cell antigen processing time is the same for both fluid-phase pinocytosis and specific receptor mediated processes, indicating that high antigen dosage is not the cause for general vs. specific antigen presentation. The present work clearly shows both general and specific presentation by B-cell clones at antigen doses comparable to levels used in experiments where the APC are normal, irradiated spleen cells. For optimum presentation lower cell number of B-cell clones was needed in spleen cells.

In conclusion, this research showed that about 50 percent of B-cell clones isolated were general presenters while the remainder responded specifically to a given antigen. Hence T-cell stimulation may be more dependent on the specificities of the APC than previously thought. These findings provide a means by which non-immune antigen presenting B cells can be immortalized and cloned. The ability to study antigen presentation by clones APC's opens up new dimensions in cellular immunology. We are using specific antigen presenting B-cell clones to determine if this specificity to a given protein operates at the submolecular level (i.e., epitopes within that protein).

In the sections which follow, other tasks are presented which outline additional ongoing research and technology efforts. Broad topical areas include crew health and medical care, environmental considerations, biomedical developments and major hardware developments.




Stability of cGMP in Plasma (A) and ANF in whole (B)




**HPLC chromatograms of spiked plasma extracts at 0 time (solid line) and after 4 days at 4 c (dot line). Upper panel, UV214nm chromatogram; lower panel, radioactivity chromatogram**

# Medical Sciences

## Significant Tasks

## The Fluid Therapy System for the Space Station Freedom Health Maintenance Facility

TM: David K. Broadwell/SD12
PI: Gerald J. Creager/SD12
Reference MS 1

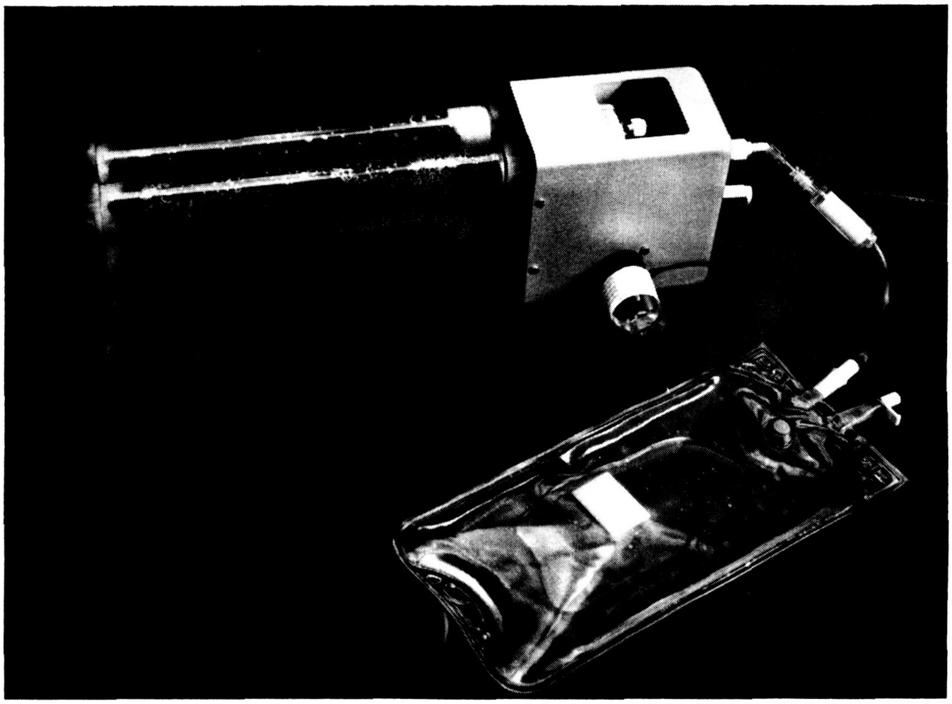
The development of the Space Station Freedom and its parts demands an innovative approach to selection of equipment, techniques, and procedures to be used in long-term missions (up to 6 months). One area requiring attention is the Fluid Therapy System for Health Maintenance Facility (HMF).

The Fluid Therapy System is necessary to provide treatment of a seriously ill or injured crewmember until he can recover or be returned via Space Shuttle to Earth for definitive treatment. In such a situation, conventional medical therapy would call for the administering of drugs or fluids by means of the intravenous (IV) route during at least a portion of the patient's treatment. Space and weight constraints limit the amount of prepackaged IV solutions which can be kept aboard the station at any one time and impact the choice of device for administering that solution. The approach taken for Freedom Station has been to reduce the volume of prepared fluids stored and to use a pump with multi-line capability.

The HMF will carry no more than six prepared IV solutions to be used in an emergency. All other IV solutions needed will be made on-orbit, using new technology and equipment designed for this purpose. The core of the system is the Sterile Water for Injection System (SWIS) developed for NASA on contract by the Sterimatics Company of Bedford, Massachusetts. This equipment will produce a minimum of 6 liters of sterile water for use in IV solutions beginning with Freedom Station's drinking water. It is a multi-constituent filtration and purification system which requires little feed pressure and is completely passive. Tap water flows into the inlet, and sterile water is collected at the outlet. An in-line device to allow formulation of IV fluids from this sterile source can be attached to the system to make the desired solution in short order. The fluid formulation technology is being investigated for NASA by the Baxter Healthcare Corporation of Rounlake, Illinois.

The fluid will be administered to the patient by an electro-mechanical pump. A pump designed and manufactured by IMED Corporation of San Diego, California, is seen as the current best prototype of the technology NASA anticipates using. This pump has the capability of providing two independent IV solutions simultaneously. It communicates with outside computers for monitoring or control and has all the standard alarms and controls found in terrestrial medical settings. In addition, the IMED pump requires no modifications to operate in the microgravity environment.

While no immediate impacts are anticipated from the technology developed for the HMF, hospitals may find some benefit in being able to stock more "IV solutions" in less space by utilizing the SWIS and the fluid formulation device. This would allow them to devote less space and manpower to maintenance of large stocks of solutions and allow more and varied solutions to be kept near the patients, making adjustments in therapy easier and quicker.



**Sterile water for Injection system (SWIS) medical development unit for Space Station Freedom HMF.**

## Electronic Stethoscope for the Health Maintenance Facility

**TM: David K. Broadwell/SD12**
**PI: John W. Gosbee/SD12**
**Reference MS 2**

The stethoscope is a key diagnostic and monitoring instrument for physicians used in both general office practice and emergency situations. For remote diagnosis in terrestrial telemedicine networks, electronic stethoscope systems have been developed which are capable of acquiring and transmitting heart, lung, and bowel sounds. An electronic stethoscope system is being developed for the Space Station Freedom Health Maintenance Facility (HMF).

An electronic stethoscope system is comprised of many critical and clinically relevant physical and electronic transformations. The bell or diaphragm head of the stethoscope amplifies the sound impulse from the patient's skin surface into the transducer (microphone). The transducer creates an analog electrical signal from the sound impulse, which is then amplified and filtered before being transmitted. The electrical signal can also be converted from analog to digital before filtering or transmission.

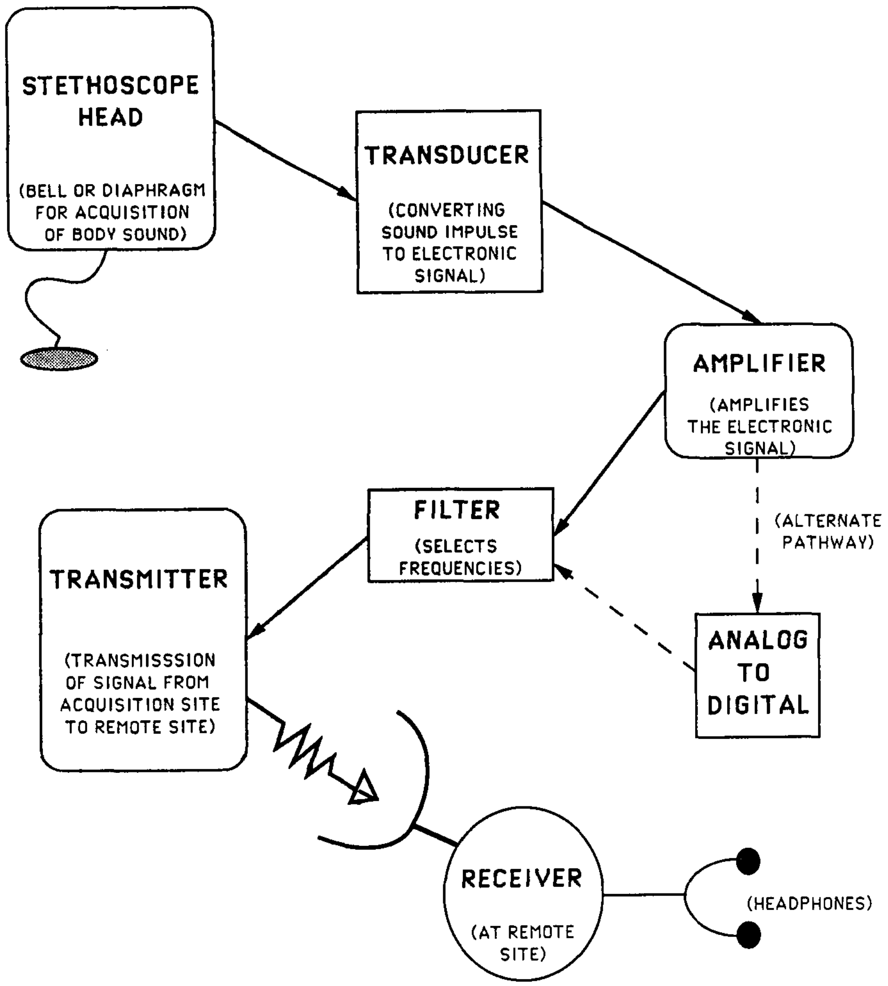
For utilization in the HMF, both clinical and technical evaluations of an electronic stethoscope system are required. Clinical assessment is necessary because diagnosis of the transmitted abnormal and normal body sounds involves a subjective interpretation by the listening physician. A technical assessment is necessary to ensure that the clinical characteristics of the body sounds are accurately transmitted. These objective "technical" considerations include:

- Frequency response and fidelity (most heart, lung, and bowel sounds have frequencies between 30 and 1000 Hz)
- Signal to noise ratio and filtering (space station ambient noise levels will usually exceed those of the body)
- Fidelity of intensity (relative sound intensity changes are diagnostic for some abnormal and normal body sounds).

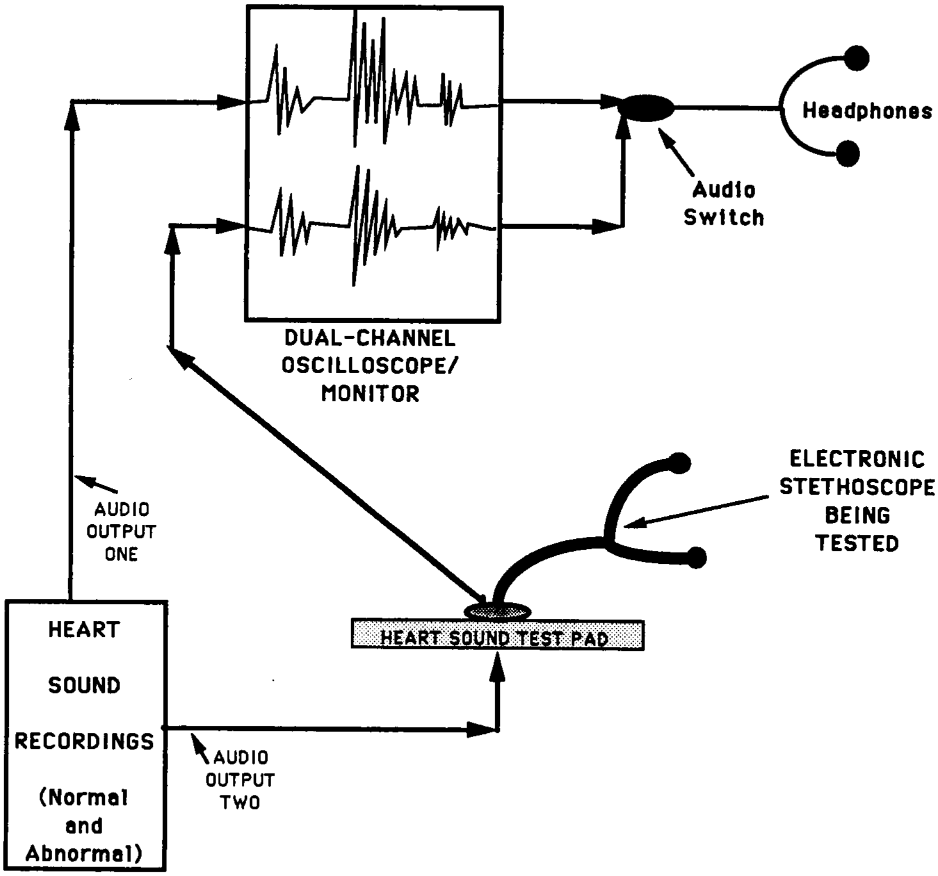
A test bed has been conceptualized to test the objective and subjective qualities of an electronic stethoscope. Abnormal and normal heart sound recordings are transmitted directly to a dual-channel oscilloscope (monitor), as well as indirectly "through" the electronic stethoscope being tested. The direct and indirect signals of sound amplitude versus time are displayed and compared on the oscilloscope. The two signals are also transmitted to an audio switch, which allows the listener to quickly switch back and forth between the two sounds for subjective (clinical) comparison.

Plans for 1989 include the following:

- Test and evaluation of several electronic stethoscope models
- Utilization of an electronic stethoscope in a HMF and mission control mock-up
- Incorporation of the needs and requirements of the HMF anesthesia subsystem, which will utilize this technology to monitor heart sounds during surgical procedures




**Electronic stethoscope system.**




Electronic stethoscope test bed.

## Microgravity Air-fluid Separator for Space Station Freedom Health Maintenance Facility

**TM: David K. Broadwell/SD12**
**PI: Bruce A. Houtchens, University of Texas Health Science Center**
**Reference MS 3**

In the delivery of medical care terrestrially, the use of suction devices to control, contain, and collect fluids is commonplace and essential. Medical suction requires: management of fluids containing a mixture of gases and liquids; management of fluids of varying viscosities, some of which may "clot" (blood and gastric contents behave differently than urine); a wide range of negative pressures; ability occasionally to achieve relatively high flow rates for brief intervals; and the option of constant or intermittent suction.

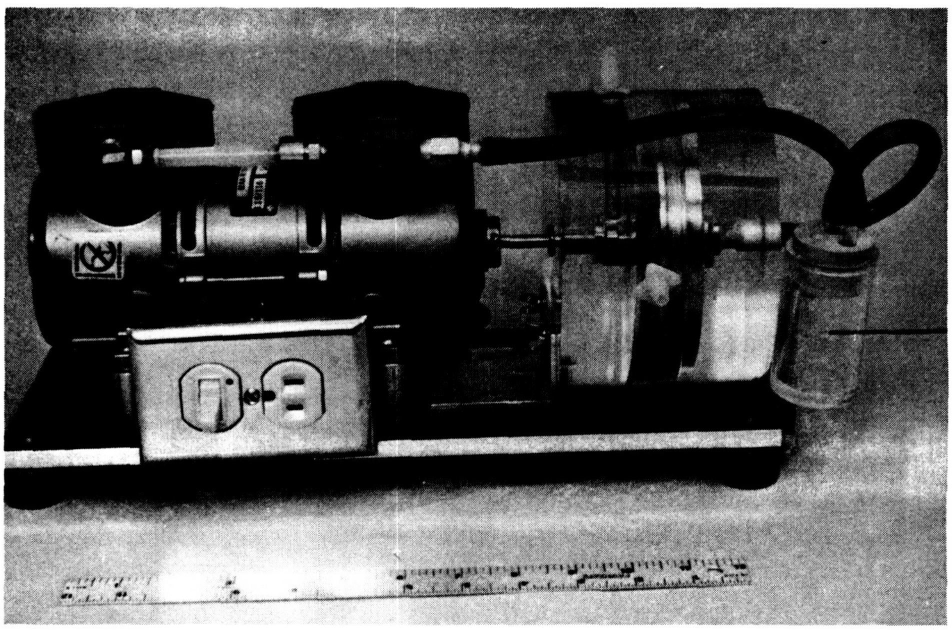
In the microgravity environment of the Space Station Freedom Health Maintenance Facility (HMF), availability of medical suction will be even more essential, and the same range of device performance will be required. Effective suction will be necessary to: maintain binocular visibility over an operative fields; permit use of "irrigation" solutions; contain "spills"; individually collect, measure, and dispose of several different kinds of biologic fluids; and facilitate safe patient transport.

Terrestrial medical suction systems utilize gravitational force and differential densities to accomplish separation of liquid from gas proximal to a negative pressure source. For HMF applications, a means independent of Earth gravity for separating liquids from gases must be used. Therefore, centrifugally-based air-fluid separator units have been designed and prototypes fabricated and tested.

In a rotating chamber of the separator unit, centrifugal force is used to distinguish the mass of liquid from that of gas: Under influence of negative pressure, liquid and gas enter the rotating chamber centrally, where the mixture comes in contact with flow channel surfaces spiralling outward to the circumference. Liquid, experiencing greater centrifugal force due to greater relative density, is propelled to the circumference of the chamber, where it encounters exit ports leading to collection bags. Gas, influenced more by the centripetal force of the negative pressure source, is attracted back to center of the chamber (via a somewhat circuitous route in order to discourage liquid from following), where it encounters an exit port leading to the vacuum source. Key variables in balancing these forces are densities of the fluids encountered, RPM and chamber radius as determinants of centrifugal force, and negative pressure as determinant of centripetal force. At about 3000 RPM, a chamber of diameter 8 inches assures separation of (water density) fluids at pressures up to -25 inches mercury. "Stacking" several units - each about 1.5 inches high, with its own pressure regulator - on the same rotating shaft, permits collection of different fluids using one motor.

For portable vacuum sources, diaphragm pumps have been chosen because of ability to generate high negative pressures with relatively low noise level. There are 28 volt D.C. models available. With optimization of fluid flow characteristics within separator chambers, it should be possible to accomplish desired uptake and separation with smaller motors. With "wall" vacuum available on space station, a motor without associated pump can be used to rotate the separator chamber(s) when operating within the HMF. For portable suction, the vacuum pump motor also rotates the chamber(s).

Prototype devices have been tested in the one g laboratory in a "worst case" orientation, such that gravity acts to encourage liquid to exit via the port leading to the vacuum pump, and in the NASA KC-135 aircraft during half minute intervals of microgravity generated by parabolic arc flight. In these circumstances, it has been possible to demonstrate consistent separation of fluids from air, without egress of liquid via the vacuum pump, and with minimum accumulation of gas in the liquid collection bags. Using computer modeling and simulation, efforts currently are in progress to optimize the geometry of the flow channels within the rotating chamber and at the exit ports, and to account for the influence of different viscosities on performance of the separator unit.



**Early prototype of microgravity air-fluid separator.**

**Table** : **Representative medical suction applications.**

| Application | Negative pressure | Type |
|---|---|---|
| Airway suction | 250 + mmHg | Constant |
| Gastric suction (N-G) | 80 mm Hg | Constant or intermittent |
| Chest tube suction | 15 mmHg | Constant |
| Active (wound) drain suction | 40 to 60 mmHg | Constant |
| Direct surgical suction | 250 mmHg | Constant |
| Suction during transport | 15 to 250 mmHg | Constant or intermittent |
| Urine collection (ambient) | 2 to 5 mmHg | Constant |
| Donor blood collection (ambient) | 2 to 5 mmHg | Constant |
| Regional laminar airflow | Low | High flow |

## Dental Diagnosis and Treatment for the Space Station Freedom Health Maintenance Facility

**TM: David K. Broadwell/SD12**
**PI: John M. Young/University of Texas Health Sciences Center, San Antonio, Texas**
**John W. Gosbee/SD12**
**Reference MS 4**

Dental emergencies pose a very real threat to the successful completion of space missions. Dental trauma, infection, and pain can be completely incapacitating and, if not properly treated, completely debilitating. Relatively simple diagnostic and treatment procedures can not only alleviate the problem but can be accomplished by crewmembers with a minimum of training and equipment.

Requirements for dental diagnosis and treatment for the Space Station Freedom Health Maintenance Facility (HMF) are being developed by John M. Young, D.D.S., University of Texas Health Science Center Dental School, San Antonio, Texas, under contract to KRUG International. Preliminary results have been obtained, which include:

- Patient/operator relationships
- Patient restraint and positioning
- Selection of a suitable rotary handpiece
- Suction/particle containment system
- Lighting requirements
- Hand-held dental instrument delivery and control difficulties

The principles of current dental practice were useful in formulating minimum requirements for the above investigations. Preliminary specifications for equipment, such as the dental hand-held tools and rotary handpiece were developed from existing instruments, while patient/operator relationships, patient positioning, and task lighting for dental procedures emulate terrestrial practice. This will both aid in training and make it safer and easier to provide ground-based instruction during in-flight dental emergencies.

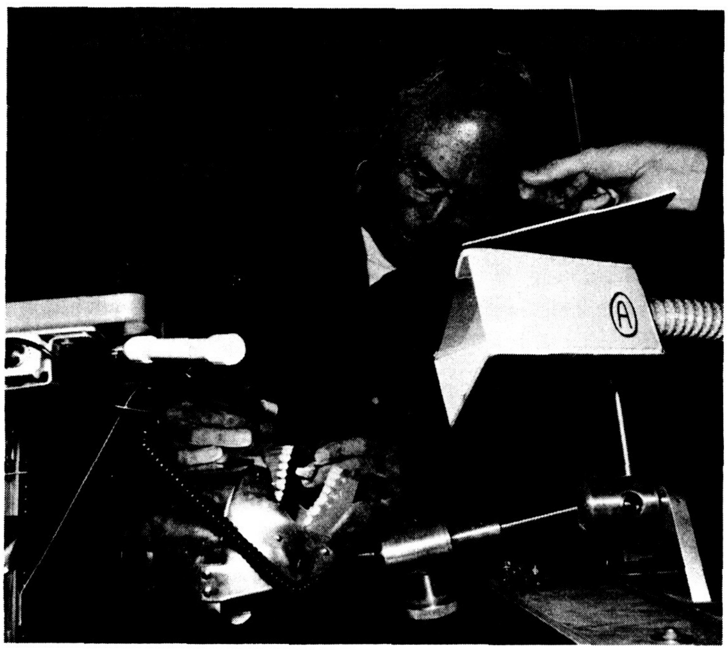
Some peculiar aspects of the space station environment were also considered. Special attention was given to weight, volume, and power limitations in the design and selection of the dental hardware, while many aspects of dental procedures themselves were adapted to a microgravity environment. In order to investigate the impact of microgravity, common dental procedures were performed, and selected equipment tested, during simulated zero gravity parabolic flight in the NASA KC-135 test aircraft. The results of these studies are highlighted below.

The performance of a dental fiber optic illumination system and dental rotary handpiece were assessed during zero g parabolic flight. Both dental systems performed well in zero g, if the operator's lower torso was firmly restrained.

A method for deployment and restraint of small dental instruments demonstrated that a dental instrument tray with magnetic inserts adequately retained the hand-held dental instruments during zero g parabolic flight.

Extensive testing was done with a prototype particle containment system designed for control of debris and aerosols generated during dental treatment. This particle containment system utilizes a laminar airflow generator that directs airflow towards a suction collection device. Two methods assessed particulate flow exiting the oral cavity and the effectiveness of the particle containment system. Initially, aerosol and particulate water were expressed from a mannequin head located beneath the containment system. Subsequently, the dental rotary handpiece and bur (drill bit) were used to "cut" resin teeth mounted in a dentoform model, which created particles and dust beneath the containment system. In both cases, the prototype particle containment system performed efficiently in directing and capturing solid and liquid particles and debris in microgravity.

In 1989, further assessment of dental diagnosis and treatment requirements for the HMF will be done on the KC-135, as well as during simulations with a HMF mock-up.

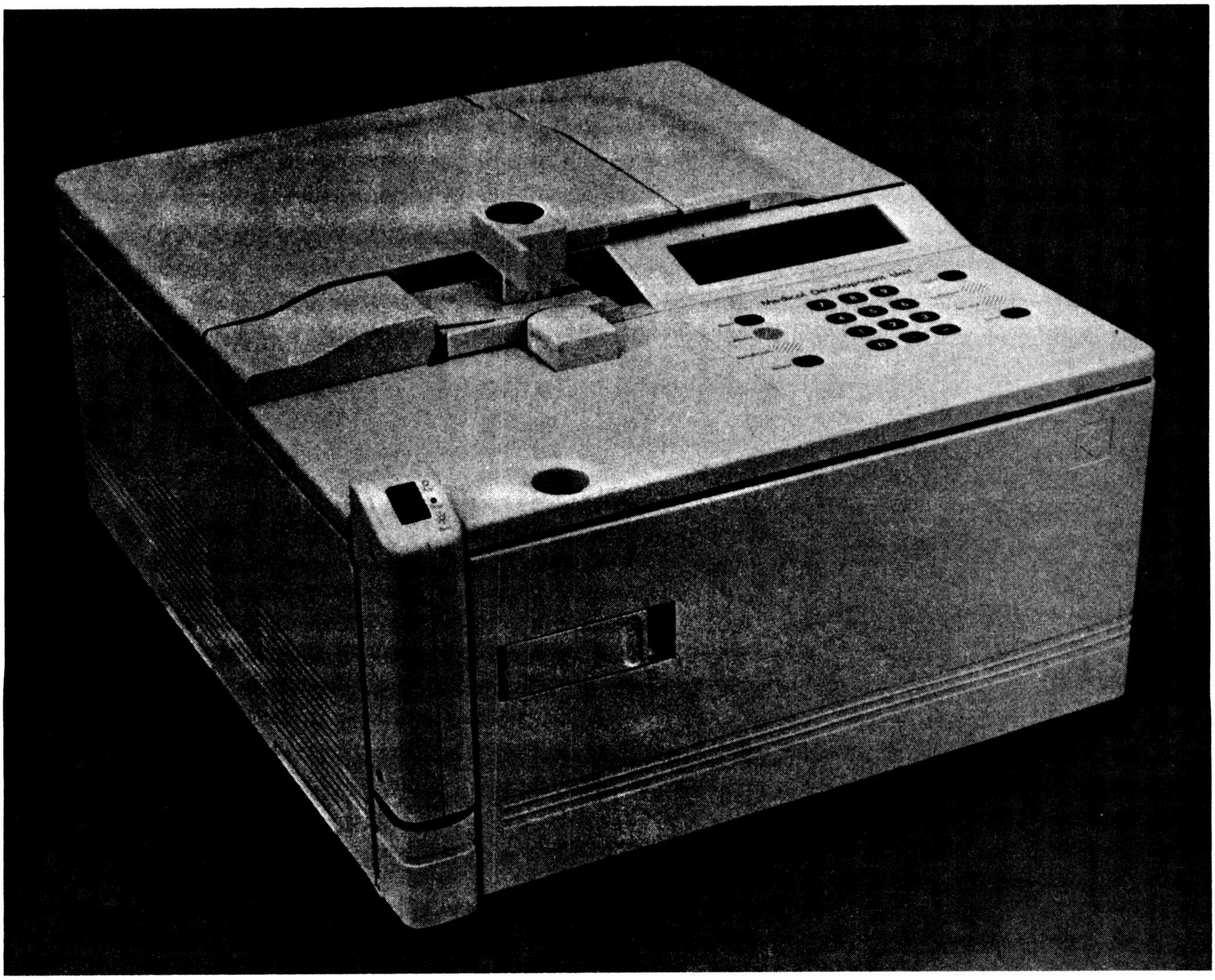



**Laminar air flow generator (L), suction collection device (R), and dental rotary hand-piece and bur drill (drill bit) cutting resin teeth mounted in a dentofoam model (C).**

Preliminary results of analysis of test solutions by Kodak and KRUG engineers using Clinical Chemistry Analyzer Medical Development Unit.

| Variable | | Na + | K + | Glu | BUN | Tbil | Trig |
|---|---|---|---|---|---|---|---|
| | | | | **Fluid 1** | | | |
| Kodak | mean | 99.0 | 1.9 | 27.1 | 9.2 | -- | 23.2 |
| | S.D. | 1.25 | 0.00 | 0.32 | 0.42 | -- | 1.86 |
| | (n = 6) | | | | | | |
| KRUG | mean | 101.3 | 2.0 | 30.5 | 10.0 | 0.0 | 29.0 |
| | S.D. | 0.50 | 0.00 | 1.73 | 0.0 | 0.0 | 6.93 |
| | (n = 4) | | | | | | |
| | | | | **Fluid 2** | | | |
| Kodak | mean | 197.7 | 9.6 | 195.2 | 56.4 | 6.8 | 185.9 |
| | S.D. | 0.48 | 0.13 | 3.05 | 1.26 | 0.26 | 2.51 |
| | (n = 6) | | | | | | |
| KRUG | mean | 200.6 | 10.0 | 216.3 | 60.0 | 8.3 | 191.3 |
| | S.D. | 0.56 | 0.47 | 1.53 | 1.00 | 0.72 | 2.08 |
| | (n = 3) | | | | | | |
| | | | | **Fluid 3** | | | |
| Kodak | mean | 156.9 | 4.9 | 426.3 | 82.2 | 14.3 | 311.8 |
| | S.D. | 1.91 | 0.11 | 5.23 | 1.64 | 0.45 | 4.32 |
| | (n = 6) | | | | | | |
| KRUG | mean | 166.8 | 5.2 | 449.0 | 84.0 | 14.9 | 320.0 |
| | S.D. | 1.71 | 0.17 | 2.24 | 2.31 | 1.03 | 8.29 |
| | (n = 4) | | | | | | |
| | | | | **Fluid 4** | | | |
| Kodak | mean | 150.2 | 6.1 | 106.6 | 30.1 | 0.8 | 181.4 |
| | S.D. | 1.08 | 0.07 | 1.69 | 0.70 | 0.05 | 2.84 |
| | (n = 6) | | | | | | |
| KRUG | mean | 153 | 6.3 | 119.5 | 31.6 | 0.9 | 189.6 |
| | S.D. | 1.83 | 0.41 | 12.35 | 0.535 | 0.19 | 9.16 |
| | | (n = 10) | (n = 10) | (n = 21) | (n = 7) | (n = 6) | (n = 10) |

Na + : sodium ion, K + : potassium ion, Glu: glucose, bil: total bilirubin, Trig: triglycerides



Clinical chemical analyzer medical development unit (MDU) for Space Station Freedom Health Maintenance Facility.

## Maintaining a Sterile Field and Sterile Technique in Microgravity

**TM:** David K. Broadwell/SD12
Charles E. Lloyd/SD12
**PI:** Katherine McCuaig/
University of Alberta,
Edmonton, Alberta, Canada
**Reference MS 6**

Numerous studies have documented the significant morbidity and mortality which can be associated with any surgical procedure, from simple intravenous cannulation to complex thoracic and abdominal operations. Complications result as much from post-operative infections as technical difficulties. The Center for Disease Control has estimated surgical wound infections, which range from minor soft tissue infections to life-threatening sepsis. The importance of the problem is demonstrated by the fact that the American College of Surgeons, the Association of Operating Room Nurses, and the Center for Disease Control have all adopted and routinely revise standards to ensure infection control and the maintenance of a sterile field and technique while performing surgical procedures.

The Space Station Health Maintenance Facility (HMF) is expected to provide the capability to diagnose and treat medical and surgical emergencies and care for an injured crewmember for up to forty-five days. Terrestrial experience has demonstrated that post-operative infectious complications can alter an uneventful recovery to a protracted, occasionally life-threatening, post-operative course requiring intravenous antibiotics and ventilatory support. Given Space Station Freedom constraints, such complications are potentially more difficult to deal with and, therefore, more serious on the HMF. To reduce morbidity and the likelihood of a costly rescue, post-operative infectious complications must be minimized. This requires the optimum maintenance of a sterile operative field and sterile technique.

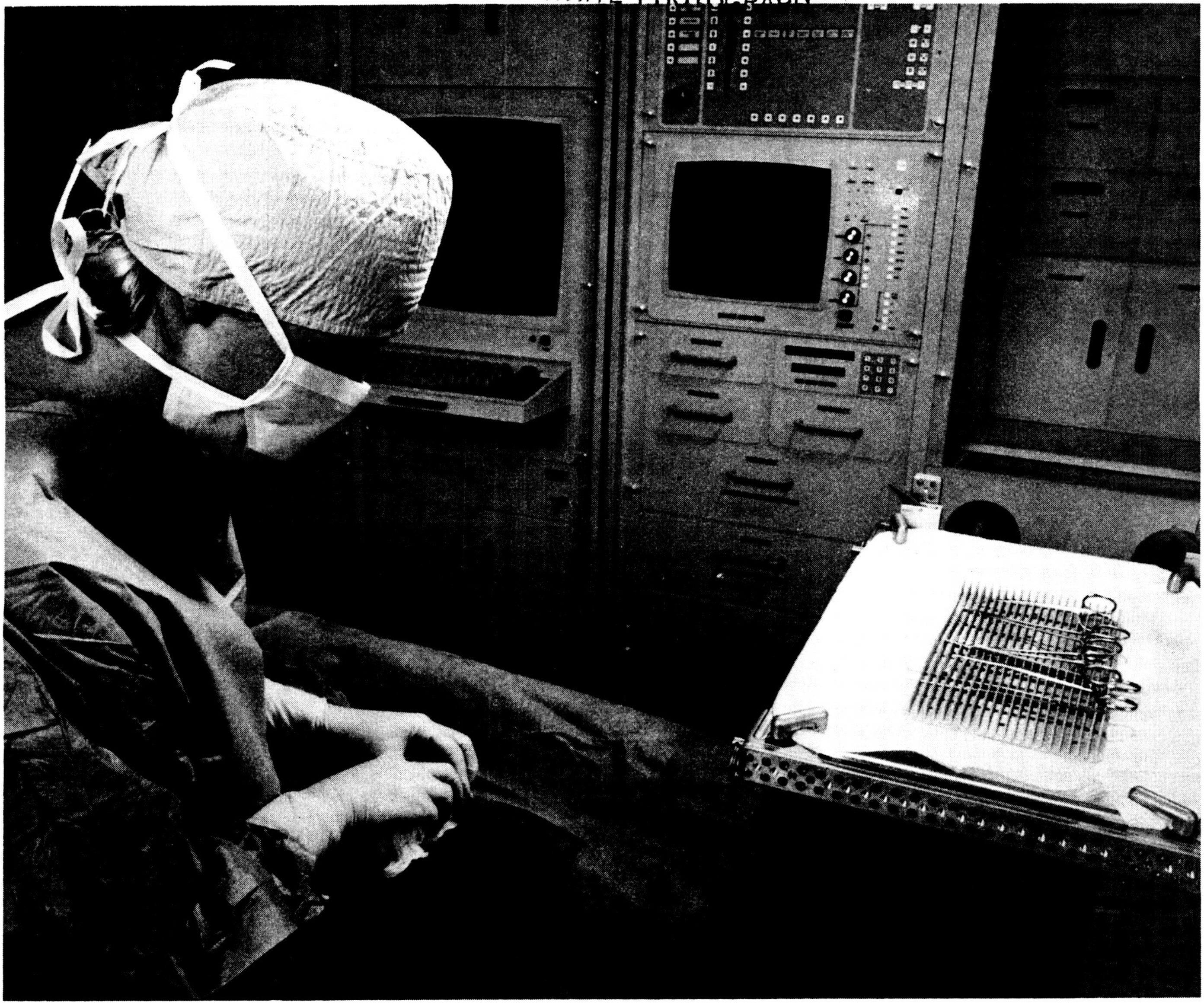
Conventional aseptic measures are designed to reduce the number of infectious micro-organisms entering the surgical wound. These include rigorous ventilation systems and laminar flow devices to reduce air-borne contamination, a surgical "scrub" with an antimicrobial soap solution to disinfect the surgeon's hands, and a surgical "prep" of the operative site with a disinfectant solution to reduce the micro-organisms normally colonizing the patient's skin. Despite a thorough scrub and prep routine, bacterial recolonization of the incision site may occur. To maintain a sterile field and reduce the risk of infection, surgical gloves, gowns, masks, caps, and drapes are utilized as mechanical barriers to isolate the operative field and reduce transmission of micro-organisms.

Despite the potentially serious consequences of post-operative infection in an injured or ill crewmember on Freedom Station, the weight and volume constraints and the microgravity environment create unique problems in maintaining a sterile field and technique. Conventional supplies are bulky and often procedure specific, aggravating the problem of limited storage and waste management. Selecting multi-use and reusable products, i.e., resterilizable drapes, may partially mitigate this. Conventional storage and access of supplies, such as gauze sponges, also have to be modified. One possible solution being tested is a versatile "storage vest" with pockets containing sterile supplies (sponges, povidone-iodine solution) to be worn by a "circulating nurse" who provides the required item to the crew medical officer as he scrubs and preps. Another option is a "jelly roll" style "prep kit" to be attached to the patient restraint system.

Particle containment is also more difficult in microgravity. Several suction devices are being tested, including a hand-held suction for localized debris and a prototype laminar flow device, presently developed for dental procedures, which may have surgical applications.

Adequate fluid containment in zero gravity also necessitates modifications of traditional sterile technique. A standard terrestrial "surgical scrub" involves repeated scrubbing and rinsing of the surgeon's forearms and hands, while the "prep" of the patient requires repeated, somewhat messy, applications of a disinfectant solution (povidone-iodine). Several prepackaged solutions have been identified and are undergoing microgravity testing, including a sterile povidone-iodine pre-soaked sponge and a newly developed water insoluble isopropyl alcohol and iodophor polymer solution with both immediate and sustained antimicrobial activity. "Rinsing" may be accomplished with individually packaged sterile water soaked sponges.

Further assessment of maintaining a sterile field and technique, including gowning, gloving, and draping will be done on NASA's KC-135 aircraft for simulating a zero gravity environment in 1989 and as part of a mid-deck experiment on Space Shuttle Flight SLS-1 in 1990.



**Maintaining a sterile field and technique.**

## Zero Gravity Eye-wash

**PI: John M. Schulz, M.D./SD2**
**Reference MS 7**

A Zero Gravity Eye-wash (ZGE) is under development by the Medical Operations Branch at the Johnson Space Center for use during National Space Transportation System (NSTS) and Space Station Freedom missions. The ZGE was developed to allow continuous irrigation of the eyes with liquids while preventing discharge of the fluid into the microgravity environment. The ZGE is designed for on-orbit use to:

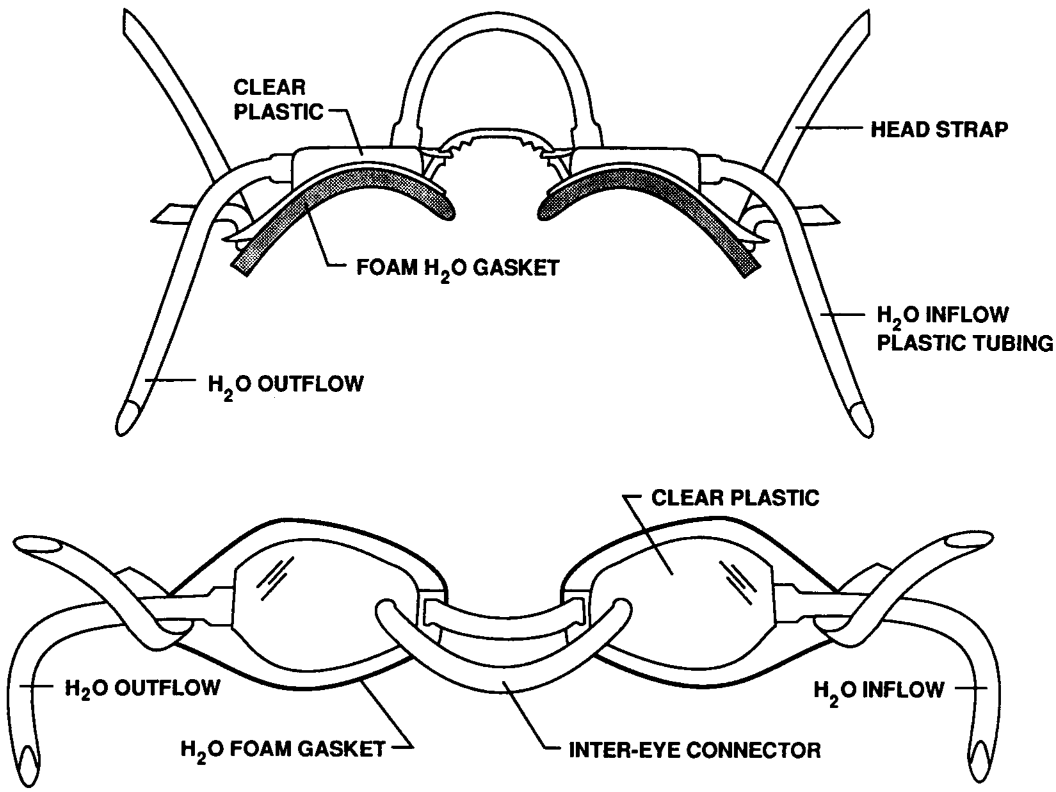
- Irrigate the eyes following an exposure to toxic chemicals
- Flush foreign bodies from the eyes
- Apply medicating fluids to the eyes
- Relieve non-specific eye irritations

Eye-washes are considered mandatory safety equipment in all laboratories in the terrestrial setting, since exposure of the eyes to certain toxic compounds can cause serious tissue damage. They are designed to provide rapid, continuous irrigation of the eyes with copious amounts of water for periods exceeding 25 minutes. The standard terrestrial eye-wash consists of a small porcelain sink designed to shoot two streams of water directly up into the eyes, allowing the runoff fluid to exit directly down the drain.

The initial focus of our development efforts has been on NSTS missions. The NSTS is utilized as a laboratory with a variety of ongoing experiments throughout routine missions. On several occasions in the past, chemicals have been released into the cabin causing minor eye irritations. The potential for a more serious exposure certainly exists. The present on-orbit therapeutic plan for a toxic eye exposure consists of directing water from a syringe or small bag across the eye to be cleaned up with towels. This is unsatisfactory, since it limits both the total amount of fluid that can be used for irrigation and the maximal flow.

The ZGE is a lightweight, compact, easy-to-apply system that allows high fluid flow rates across the eyes without releasing fluid into the environment. It consists of a set of modified swim goggles that provides an inflow of water across one or both eyes and an outflow to an appropriate collection system. Plans for utilization during NSTS missions include using the Potable Water Auxiliary Port in the galley as a water source and the Waste Collection System, urine collection device, for discarding the water. This will allow the necessary continuous flow of water across the eyes for extended periods without release into the microgravity environment. A prototype device, using a three liter bag of sterile water as a source and an empty bag for collection, has been satisfactorily tested during simulated zero-gravity maneuvers in NASA's KC-135 aircraft.


**Zero gravity eyewash prototype using a three-liter bag of sterile water as a source and an empty bag for collection.**




**Modified swim goggles provide inflow of water across one or both eyes and an outflow to an appropriate collection system.**

## Operational Toxicology Database for the National Space Transportation System

PI: John Schulz, M.D./SD2
CI: Nancy Henry/SD2
Stephen Marah/SD2
Jan Carr/SD2
Reference MS 8

An operational Medical Toxicology Database has been developed by the Medical Operations Branch at the Johnson Space Center for use in Mission Control during National Space Transportation System missions. It was designed to address contingency toxic exposures and provide rapid access to information on potential onboard toxins, as well as NSTS specific medical treatment options.

The Orbiter utilizes fuels, oxidizers, ammonia, hydraulic fluids, coolants, and a variety of other potentially hazardous utility compounds during routine operations. Exposure of crewmembers or ground personnel to these compounds, or chemicals associated with onboard experiments, is not an impossibility.

The first problem during a contingency toxic exposure lies in identification of the compound. The Medical Toxicology Database provides search capabilities based on:

- Physical characteristics of the compound
- Location of the compound or experiment within the Orbiter, and/or
- Patient symptomatology

Once the compound is successfully identified, the data base provides information on unique characteristics and hazards of the compound, exposure limits, clean-up procedures, and NSTS specific medical treatment. The NSTS specific medical treatments are based on:

- The diagnostic and therapeutic aids carried in the Space Shuttle Orbiter Medical System
- The training of the Crew Medical Officer
- The Medical Checklist (Flight Data File) carried onboard the Orbiter

During a contingency exposure, the designated Crew Medical Officer on-orbit would relay pertinent information, regarding both the toxin and the patient, to the Flight Surgeon on console at Mission Control. The Flight Surgeon would immediately access the Medical Toxicology Database and relay appropriate information regarding the compound, as well as procedures for clean-up and medical treatment, as indicated.

The Medical Toxicology Database is based on toxicology information obtained from a data base provided by the Biomedical Laboratory Branch and medical treatments derived from TOMES (TM), a medical information system developed by Micromedex, Inc. It is run on a standard personal computer using the data base, Advanced Revelation.

**Example:**

INHALATION INJURY TREATMENT PROTOCOL

1. Remove individual from further exposure.

2. If needed, don the LES helmet to stop further exposure. Signs of toxicity may be delayed several hours in some cases.

3. For respiratory distress: Refer CMO to MEDICAL CHECKLIST - CPR Station (page 3-7).
   a. Ensure airway clear - if indicated:
      i. chin lift or jaw thrust
      ii. if unconscious , insert Oral Airway (EMK C1-3)
      iii. if unable to clear airway, refer CMO to MEDICAL CHECKLIST - CRICOTHYROTOMY TECHNIQUE (page 3-5).
   b. Provide supplemental 02:
      i. if awake and breathing adequately without assistance - LES Helmet
      ii. otherwise, Resuscitator (MED KIT LOCKER) connected to Orbiter 02 (M032M, M069M, or C6 Orbiter 02 connections)
      iii. confirm proper flow of 02
   c. Evaluate Breathing - mechanically ventilate, with resuscitator, as indicated.

   d. For bronchoconstriction/ asthma: (Refer CMO to MEDICAL CHECKLIST - Drug Administration Technique - Intramuscular page 4-10)
      Load Tubex injector (EMK B1-2) with one or more of the following, as indicated:
         Epinephrine, 1:1000, 1 cc unit (EMK A2-1.2.3.4.5) - .3-.5 cc SQ
         Benadryl, 50 mg/cc, 1 cc unit (EMK A1-5,6) - 1 cc IM
         Decadron, 4 mg/cc, 2.5 cc unit (EMK D1-1,2) - 2 cc IM

***DO NOT ADMINISTER EPINEPHRINE IF EXPOSURE TO***
HALOGENATED HYDROCARBONS (I.E. HYDRAZINE).

4. For prophylaxis or indications of infection or sepsis (fever, cough, increased dyspnea):
   a. If taking PO, one of the following:
      Amoxicillin, 500 mg (MBK E1-7) - 1tab PO q 8 hrs.
      Erythromycin, 250 mg (MBK E1-8) - 2 tabs PO q 6 hrs.
   b. If unable to take PO:
      Amikacin, 250 mg/cc 2 cc unit (EMK A1-16) - 15 mg/kg/day given in three doses.

## Medical Operations Medical Records Database System

TM: Jeffrey Davis, M.D./SD2
PI's: Sam Pool, M.D./SD
Larry Pepper, D.O./SD2
Steve Marah/SD2
Anthony Cipolla/SD2
Reference MS 9

A comprehensive medical records database system is being developed by the Johnson Space Center Medical Operations Branch for use in storing, accessing, and researching medical data for the Longitudinal Study of Astronaut Health as well as daily medical clinical activities. The data base was designed to address the many problems inherent in the standard paper medical record.

Standard medical charts include a multitude of papers involving annual examinations, physician notes and recommendations, results of laboratory tests, X-ray procedures, and other diagnostic tests, and letters from referral physicians. Standard medical charts may vary, but all lack a usable format for simple or complex clinical research. Simple research might involve accessing data on an individual patient such as cholesterol data and cardiac risk. More complex clinical research might involve multifactorial analysis of risk factors involved in the occupation of space flight.

The data base was designed from its inception to be extremely user-friendly in order for it to be utilized by a variety of health care providers. Security of data is maintained through a multi-level user-dependent password system. The data base is composed of multiple clinical modules interrelated through the use of a rational data base. Example modules include the exam module, laboratory module, preventive medicine module, and clinical summary module. Each module contains specific data entry/review screens, including summary graphics capabilities. By utilizing a relational data base, the physician can access a variety of variables for clinical research. Specific data review screens were developed for access to data utilized in daily clinical care. Additionally, data display screens can be customized to display specific variables that the physician requests, using minimal software modifications.

The Medical Operations Medical Records Database is currently operated on a personal computer local area network (LAN) with a file server (personal computer (80386b processor)), a 300 megabyte hard disk storage system, and a tape back-up system. Additional software provided on the LAN includes word processing, mail system, and other National Space Transportation System specific database software (Medical Toxicology Database for the National Space Transportation System).

## Exercise as a Countermeasure for Microgravity-Induced Deconditioning

**PI's: Steven F. Siconolfi Ph.D./SD5**
**Bernard A. Harris, Jr., M.D./SD5**
**Reference MS 10**

The human body's natural adaptation to the reduced physiological demands of microgravity results in cardiovascular, musculoskeletal, and neuromuscular deconditioning. Deconditioning results in loss of aerobic and anaerobic fitness, which in turn produces loss of muscle strength and endurance. Deconditioning also produces orthostatic intolerance and detrimental changes in body composition (loss of muscle mass, decreased bone density, loss of body calcium, etc.). Operationally, deconditioning produces functional problems during space flight, such as declines in crew work capacity, decreases in landing proficiency, and difficulty readjusting to one g forces. The rationale for developing countermeasures is to prevent these operational difficulties by interrupting the body's natural attempts to adapt to zero g, thus assuring the crewmember's healthy return to one g.

Other potential deterrents to deconditioning, such as lower body negative pressure and saline loading (cardiovascular) and fluoride and calcium supplementation (bone demineralization), have been explored. Although these measures can be effective, they have proven to be of narrow scope. In contrast, exercise can potentially retard the combined cardiovascular, musculoskeletal and neuromuscular effects of adaptation. The Exercise Countermeasures Project is exploring the specific physiological effects of exercise with the goal of developing an exercise program that can be performed in-flight to minimize or deter deconditioning. Products of the project will include specialized exercise equipment and individualized exercise "prescriptions" designed to be used onboard Space Shuttle and space station.

In collaboration with the Artificial Intelligence Laboratory, the Exercise Countermeasures Project developed a computer-controlled software package that is capable of automatically adjusting the difficulty of an exercise session as training progresses. Normally, exercise rates are calculated from estimates of an individual's maximum energy expenditure, and thus must be continuously recalculated as training (or deconditioning) progresses. The computer is also better at maintaining exercising individuals in their "target zones" in terms of heart rate and energy expenditure than a human controller. These computer-controlled devices will lessen space vehicles' dependence upon real-time datalinks for exercise monitoring.

Other projects performed during 1988 included collaborative studies with the Anthropometry and Biomechanics Laboratory on external forces during aerobic exercise on a treadmill. Preliminary results from this study suggest that both footstrike forces and muscle activity are strongly affected by the speed and incline of the treadmill as well as by gravity. Thus, exercise countermeasures will depend upon local biomechanical factors as well as metabolic workloads.

Another study examined the value of circuit weight training in maintaining muscular endurance and strength. Moderate levels of circuit weight training increased muscular endurance and strength. Returning to normal activities after this type of training, resulted in decreased endurance, but no loss in strength. Consequently, training that maintains muscular endurance will be a key ingredient in exercise prescriptions for space flight.

**Biomechanical evaluation of walking in zero gravity.**

## Space Station Freedom Exercise Countermeasure Facility (ECF) Knowledge-Based System for Monitoring Non-Invasive Physiological Data and Advising Exercise Countermeasures

**PI: Laurie Webster/EF5**
**Reference MS 11**

The U.S. Space policy includes the development of a permanently manned space station and a long-range goal of expanding human presence and activity beyond Earth orbit into the solar system. The microgravity environment of space flight produces rapid cardiovascular changes, as well as other physiological changes, which are adaptive and appropriate in that setting, but are associated with significant deconditioning and orthostatic hypotension on return to Earth's gravity. Despite more than 25 years of experience with manned space flight of both short and long duration, the specific stimuli for these changes and their underlying pathophysiology are poorly understood. Research concerned with the physiological adaptation of man to a weightless environment of space is replete with special challenges. This adaptation includes the loss of skeletal calcium, of muscle mass and nitrogen stores, and of red cell mass and blood volume. Also, decrements in exercise capacity and orthostatic tolerances are seen after extended periods of weightlessness. The well-being of space station personnel requires attention to and a clear understanding of their physiological and psychological adjustments to life on Earth, after their return.

The proposed Space Station Freedom, now under development by NASA, is planned to be a highly automated vehicle, capable of more autonomous operation than any previous manned space platform. One proposed method for decreasing the space station's dependence on continuous ground support is to integrate "onboard experts," in the form of dedicated expert systems, into the normal station operation decision loop. In keeping with this "autonomous operations" concept, an expert system for analyzing non-invasive physiological measurements of deconditioning and establishing from a one g baseline exercise stress test, an initial exercise prescription, as well as managing the needed modifications to this initial prescription (as the need arises in microgravity), is being developed. This knowledge-based expert system will tailor the exercise prescription to each crewmember based on the crewmember's past performances with a prescribed regime; expected/accepted levels of deconditioning in microgravity as determined from physiological models; and the crewmember's specific conditioning goals.

The problem is that these dedicated expert systems, such as the one described (particularly since it is in a medical diagnostic category), will not be permitted to be used for medical or critical real-time applications on the Space Station Freedom, until a mechanism/technology is in place to evaluate their performance. It must be proven that they will not make catastrophic errors and that they will follow a path of reasoning like that of the experts.

The focus of this research will involve the investigation of Artificial Intelligence (AI) technology and its use in providing an in-flight Exercise Prescription Management Expert System. Requirements will be established for database management and analysis. Specifically, the research will:

- provide an effective and "intelligent" exercise system onboard the orbiter and Space Station Freedom
- develop a reliable, flexible monitoring and control system for the Exercise Countermeasure System (ECS)
- develop a data acquisition system for research on physiological effects of long-term and repeated exposure to zero g, and an exercise countermeasure
- provide a test bed of exercise protocols, physiological models, and motivational displays
- integrate knowledge-based AI systems with Space Station Freedom's Data Management System (DMS)

AI technology, including evidential reasoning, belief functions, and explanation will be employed to implement an automated validation system.

Also, other technologies to be explored are:

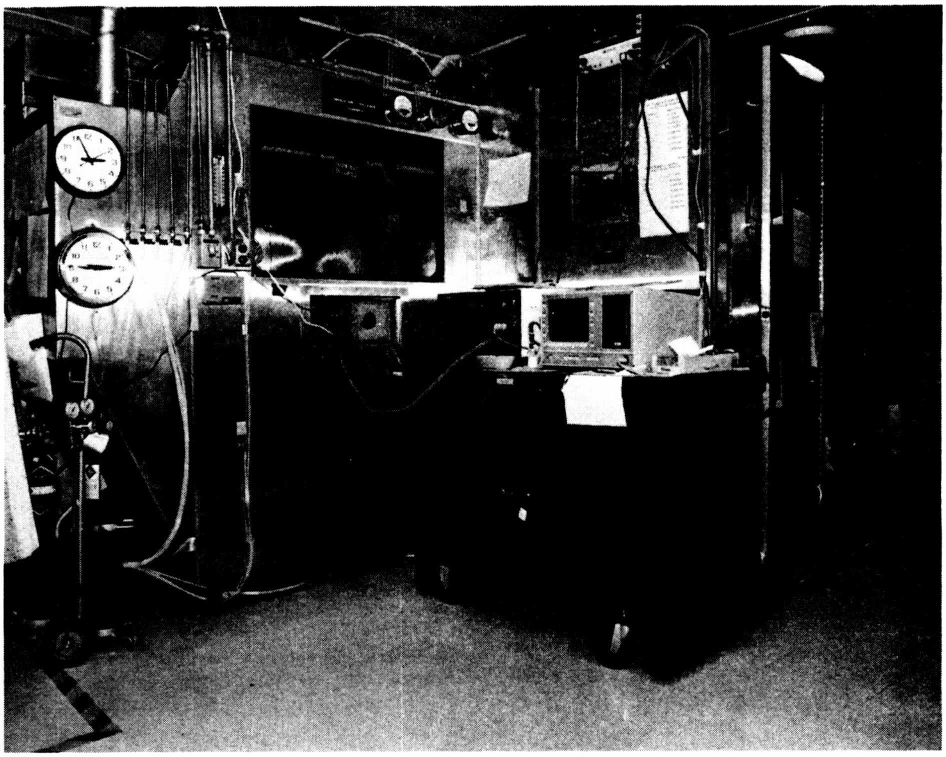
- use of alternatives to keyboard entry, such as natural language speech recognition, and voice synthesis
- use of laser discs to provide computer-controlled interactive videos during exercise.

## Halon 1301 Human Inhalation Exposure Study: Study Overview and Toxicokinetic Evaluation of Halon 1301 in the Exposed Subjects

**TM: Duane L. Pierson, Ph.D./SD4**
**PI: Chiu-Wing Lam, Ph.D./SD4**
**Theodore J. Galen/SD4**
**Reference MS 12**

Halon 1301 (Bromotrifluoromethane) is widely used as a fire-extinguishant and is employed in the Space Shuttle fire suppression system. If a fire, a potential fire, or a faulty alarm occurs, Halon 1301 could be discharged, resulting in a concentration of up to 1 percent in the crew module. No decontamination systems onboard could effectively remove Halon 1301 from the breathing atmosphere. The crew could be exposed to Halon 1301 until the Orbiter returns to Earth. At high concentrations, Halon 1301 exerts toxic effects primarily on the central nervous and cardiovascular systems. However, existing toxicologic data are insufficient to allow assessment of the effects on humans upon prolonged exposures to Halon 1301. Thus, NASA sponsored a 24-hour Halon 1301 inhalation exposure study on humans. Investigators and support staff were enlisted from NASA, KRUG International, Methodist Hospital, and the University of Texas School of Public Health in Houston. Four pairs of test subjects participated in this study, using a 4.48 $m^3$ inhalation chamber. Each pair was exposed in a double-blind fashion for 24 hours to 1 percent Halon 1301 and to air in two separate exposures approximately one week apart. Performance battery tests were administered; clinical chemistries and cardiac and pulmonary functions were measured.

As part of the overall study, blood and breath samples were collected at several time points during and after each exposure to examine the toxicokinetics of Halon 1301 in the body. Results from toxicokinetic evaluation indicated that blood Halon 1301 levels reached a steady state within 2 hours, and the steady state concentrations (SSC) in the blood of the eight test subjects were 3-4 μg/ml. Six hours after the exposure, the blood Halon 1301 concentration was about 10 percent of the SSC. Breath samples collected during exposure reflected the chamber concentration relatively closely. After the exposure was terminated, blood and breath showed an initial fast phase of Halon 1301 elimination, followed by a slow phase of elimination. the fast and slow elimination phases probably reflect the excretion of Halon 1301 from the well-perfused tissues and slow-perfused tissues (such as fat), respectively. The toxicokinetics of Halon 1301 in the body are similar to those of other water-insoluble organic gases or solvents. The blood Halon 1301 concentrations (SSC) observed in the present study agree well with those reported in the literature, Harrison et al., *J. Soc. Occup. Med. 32, 1982*; Mullin et al., *Amer. Ind. Hyg. Asso.* 40, 1979.



**Inhalation exposure chamber.**

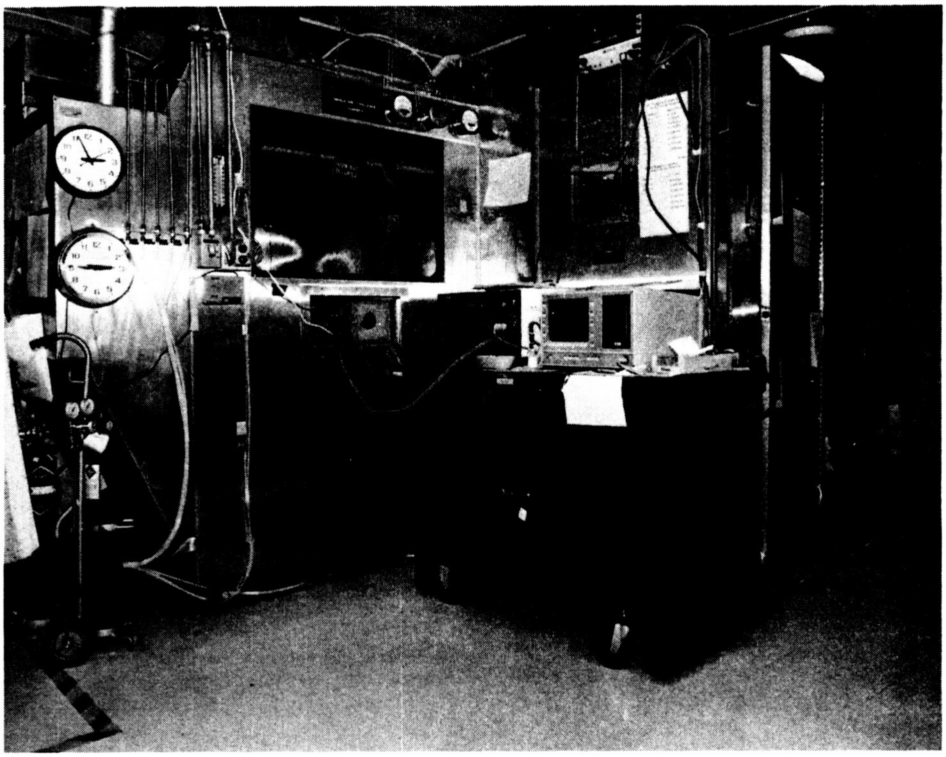
One g baseline stress test.

## Halon 1301 Human Inhalation Exposure Study: Study Overview and Toxicokinetic Evaluation of Halon 1301 in the Exposed Subjects

**TM:** Duane L. Pierson, Ph.D./SD4
**PI:** Chiu-Wing Lam, Ph.D./SD4
Theodore J. Galen/SD4
**Reference MS 12**

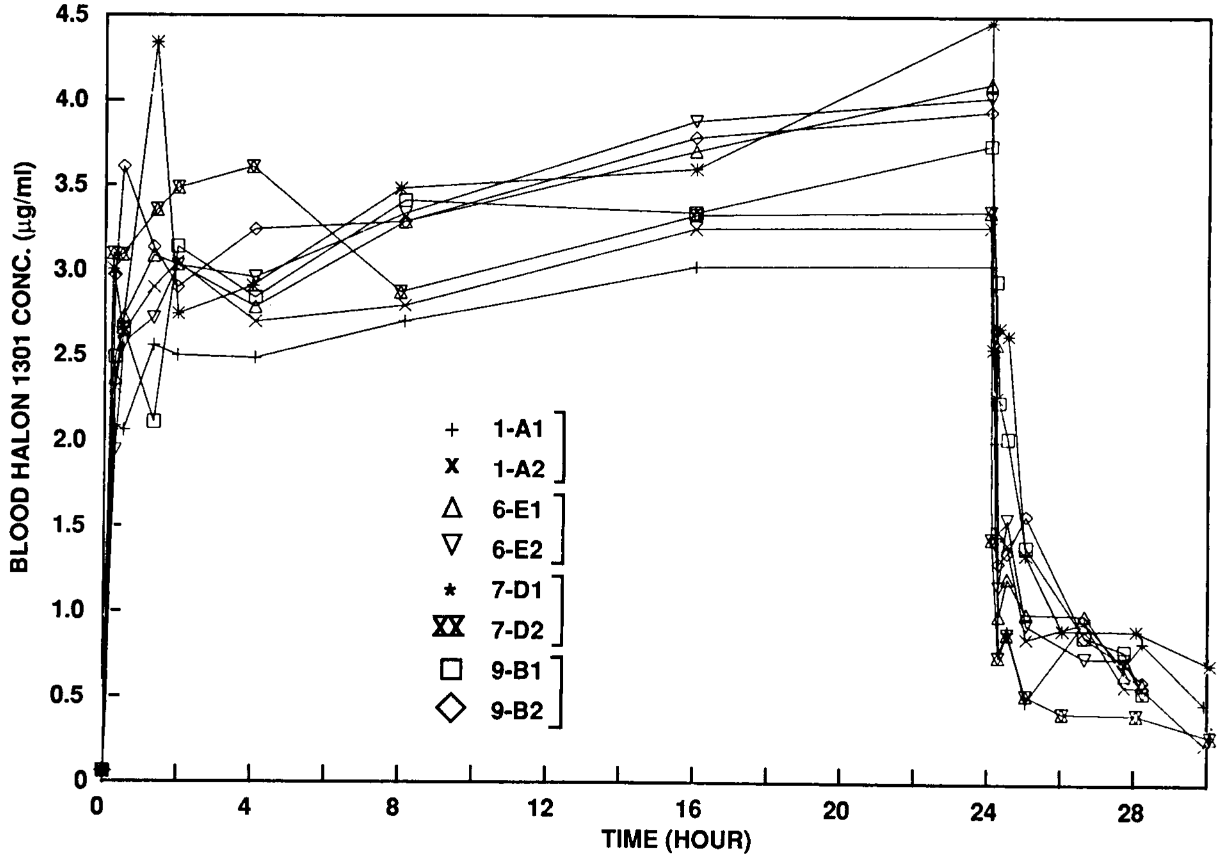
Halon 1301 (Bromotrifluoromethane) is widely used as a fire-extinguishant and is employed in the Space Shuttle fire suppression system. If a fire, a potential fire, or a faulty alarm occurs, Halon 1301 could be discharged, resulting in a concentration of up to 1 percent in the crew module. No decontamination systems onboard could effectively remove Halon 1301 from the breathing atmosphere. The crew could be exposed to Halon 1301 until the Orbiter returns to Earth. At high concentrations, Halon 1301 exerts toxic effects primarily on the central nervous and cardiovascular systems. However, existing toxicologic data are insufficient to allow assessment of the effects on humans upon prolonged exposures to Halon 1301. Thus, NASA sponsored a 24-hour Halon 1301 inhalation exposure study on humans. Investigators and support staff were enlisted from NASA, KRUG International, Methodist Hospital, and the University of Texas School of Public Health in Houston. Four pairs of test subjects participated in this study, using a 4.48 $m^3$ inhalation chamber. Each pair was exposed in a double-blind fashion for 24 hours to 1 percent Halon 1301 and to air in two separate exposures approximately one week apart. Performance battery tests were administered; clinical chemistries and cardiac and pulmonary functions were measured.

As part of the overall study, blood and breath samples were collected at several time points during and after each exposure to examine the toxicokinetics of Halon 1301 in the body. Results from toxicokinetic evaluation indicated that blood Halon 1301 levels reached a steady state within 2 hours, and the steady state concentrations (SSC) in the blood of the eight test subjects were 3-4 μg/ml. Six hours after the exposure, the blood Halon 1301 concentration was about 10 percent of the SSC. Breath samples collected during exposure reflected the chamber concentration relatively closely. After the exposure was terminated, blood and breath showed an initial fast phase of Halon 1301 elimination, followed by a slow phase of elimination. the fast and slow elimination phases probably reflect the excretion of Halon 1301 from the well-perfused tissues and slow-perfused tissues (such as fat), respectively. The toxicokinetics of Halon 1301 in the body are similar to those of other water-insoluble organic gases or solvents. The blood Halon 1301 concentrations (SSC) observed in the present study agree well with those reported in the literature, Harrison et al., *J. Soc. Occup. Med. 32, 1982*; Mullin et al., *Amer. Ind. Hyg. Asso.* 40, 1979.



**Inhalation exposure chamber.**

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH




Halon 1301 concentrations in the blood of exposed subject pairs. Each pair was exposed for 24 hours to 1 percent Halon 1301.

## Universal Sample Inlet System for Gas Chromatography-Mass Spectrometer Systems

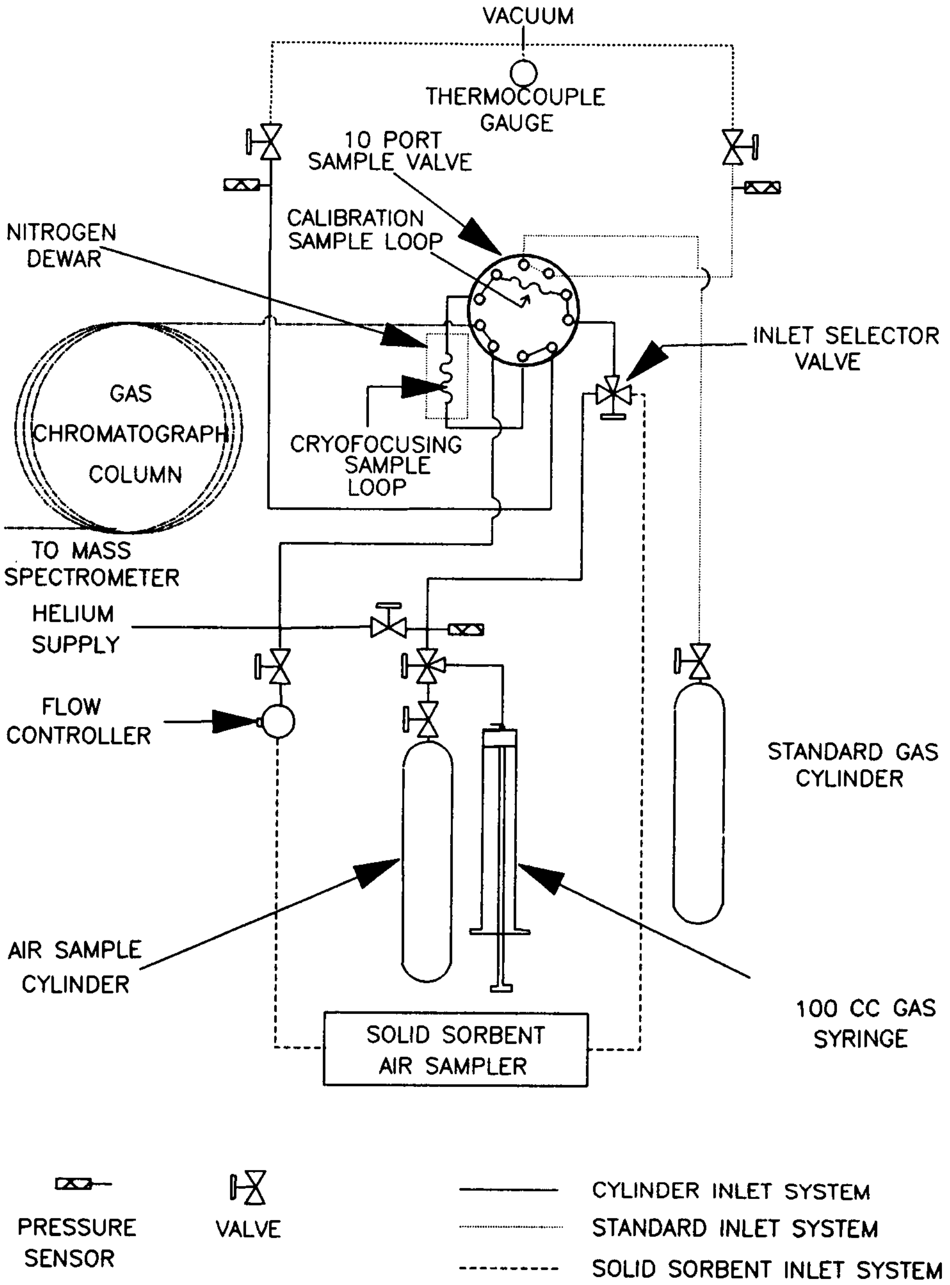
**TM: Duane L. Pierson, Ph.D./SD4**
**PI: Theodore J. Galen/SD4**
**Reference MS 13**

The presence of trace level volatile organic compounds in the spacecraft atmosphere can have serious environmental implications. In the Space Shuttle ECLSS system, the atmosphere within the crew module is recycled through scrubbers containing lithium hydroxide to remove the carbon dioxide. A small quantity of charcoal is also present in the scrubbers to remove organic compounds. To monitor the effectiveness of this process and to identify the organic compounds that a flight crew is exposed to during a mission, middeck air samples are collected both pre- and inflight for gas chromatography-mass spectrometer analysis. These samples are collected in one of two ways: with the Air Sample Cylinders which are pressurized with a sample of spacecraft atmosphere from approximately 10 to several hundred psi or with the Solid Sorbent Air Sampler (DTO 623) which adsorbs organic compounds onto a porous polymer. The samples are analyzed in the Toxicology Laboratory of the Biomedical Laboratories Branch at the Johnson Space Center (JSC) by gas chromatography-mass spectrometry. The first step in the analysis procedure is to transfer the sample from its respective container or from the porous polymer to the inlet of the gas chromatograph. A unique Universal Sample Inlet System for a gas chromatograph-mass spectrometer has been designed, developed, and constructed by the Toxicology Laboratory of the Biomedical Laboratories Branch at JSC.

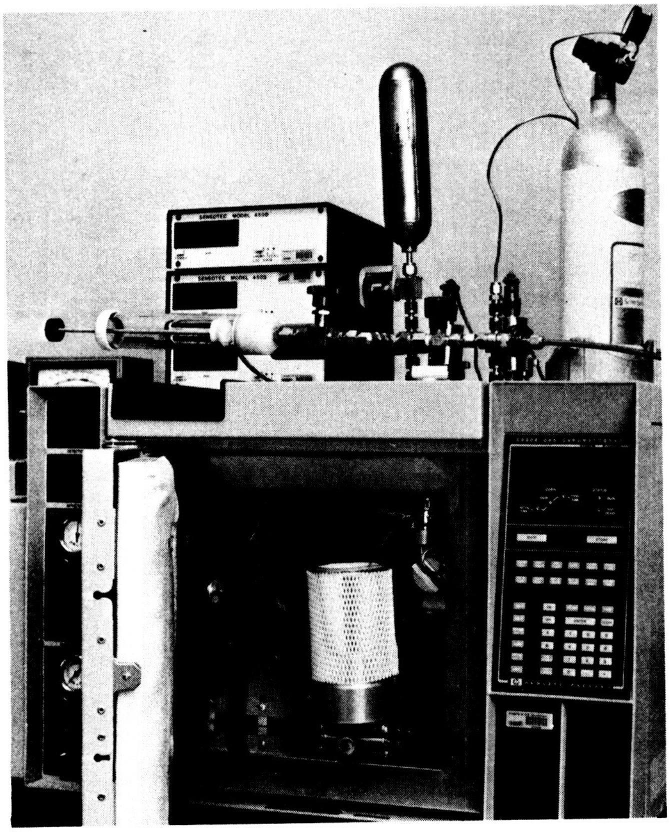
In the standard commercial laboratory, the transfer procedure usually is performed with a syringe which is used to remove the sample from the cylinder and to subsequently inject it from the rubber septum of the inlet to the gas chromatograph. If the pressure in the cylinder is significantly greater than atmospheric pressure (14.7 psi), then a portion of the gas can be purged through a gas sampling valve for introduction into the analytical instrumentation. In either case, gas samples in cylinders which do not contain pressures greater than atmospheric pressure cannot be analyzed. In addition, the syringe transfer process is cumbersome and likely to contaminate the sample.

To avoid the problems associated with this kind of transfer technique the Universal Sample Inlet System was developed in the JSC Toxicology Laboratory. The Universal Sample Inlet System provides the hardware to transfer gas samples from both low and high pressure (five to several hundred psi), and a means to introduce standard gas mixtures for calibration purposes. The system insures that the sample is quantitatively transferred and that analytical resolution is maintained. In addition the inlet system can be directly coupled to the Solid Sorbent Air Sampler for direct transfer of organic material trapped on porous polymers or other adsorbents. The inlet is constructed around a 10-port valve and includes digital pressure sensors, heated transfer lines and a vacuum utility. It also incorporates a liquid nitrogen cryo-focusing loop which is used to condense the organic compounds in the sample while not condensing the oxygen and nitrogen. When the liquid nitrogen cooling is removed from the cyro-focusing loop, the condensed organic compounds vaporize into the helium carrier gas flow to the gas chromatograph.

Once the sample cylinder or solid sorbent device is connected to the inlet system, the overall operation of the system is simply a process of valve position changes. The diagram of the sample inlet system summarizes the operation in acquiring data from prepared standard gas mixtures, cylinder air samples at various pressures and from porous polymers. When calibrating the gas chromatograph-mass spectrometer with a standard gas mixture, the standard gas cylinder is connected to the 10-port sample valve and the calibration sample loop is then pressurized to a predetermined amount by monitoring the pressure sensors. The sample loop is then put in series with the liquid nitrogen cooled cryo-focusing loop by rotating the sample valve. The standard organic compounds are condensed in a narrow band ready for transfer to the gas chromatographic column. The condensed standard is then moved into the chromatographic column by rotating the 10-port sample valve and removing the liquid nitrogen cooling. This vaporizes the standard and transfers it from the cryo-focusing loop to the gas chromatographic analytical column. Cylinder air samples and Solid Sorbent Air Sampler tubes may be analyzed in a similar manner. Once the inlet selector valve is set to the desired position, the sample is transferred directly to the cryo-focusing loop where the volatiles are condensed. The condensed compounds are then volatilized, quantitatively transferred in a concentrated narrow band to the chromatographic column, separated and subsequently analyzed by the mass spectrometer.

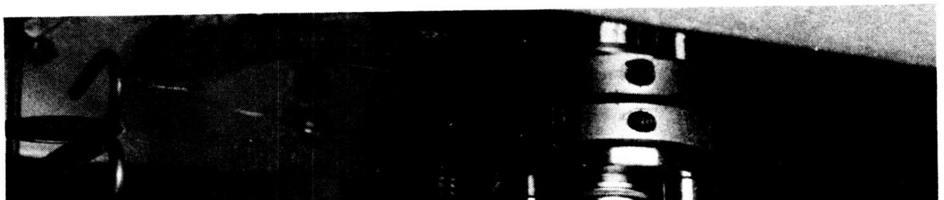



**Functional diagram of the universal sample inlet system.**



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

The universal sample inlet system installed on Toxicology Laboratory gas chromatograph-mass spectrometer system: (left to right) gas syringe, air sample cylinder, standard gas cylinder and the liquid nitrogen dewar inside the gas chromatograph oven.



Closeup view of the 10-port valve, calibration sample loop and the inlet selector valve. All of the above are mounted in the gas chromatograph oven.

## Water System Test Bed Supporting Long-Duration Space Flight

**TM: Richard L. Sauer, P.E./SD4**
**PI: John R. Schultz, Ph.D./SD4**
**David T. Flanagan/SD4**
**Randall E. Gibbons/SD4**
**Harlan D. Brown, Ph.D./SD4**
**Robert D. Taylor, Ph.D./SD4**
**Duane L. Pierson, Ph.D./SD4**
**Reference MS 14**

The Water and Food Analysis Laboratory at the Johnson Space Center has the responsibility for ensuring that potable and hygiene water systems for use on long-duration spaceflights meet specifications for crew health. Aboard Space Station Freedom and on an exploratory trip to Mars, the ability to recycle used waters to potable quality is a necessity. The ability to recycle water from humidity condensate, wash water, or similar sources, as is planned for long-term flights, is unproven technology. In addition, since water microbial quality requirements for the space station are especially stringent (a total bacterial count of not more than 1 colony-forming unit per 100 mL of water examined), the maintenance of water quality in a simulated spacecraft water system merits a high priority effort and is undergoing extensive studies.

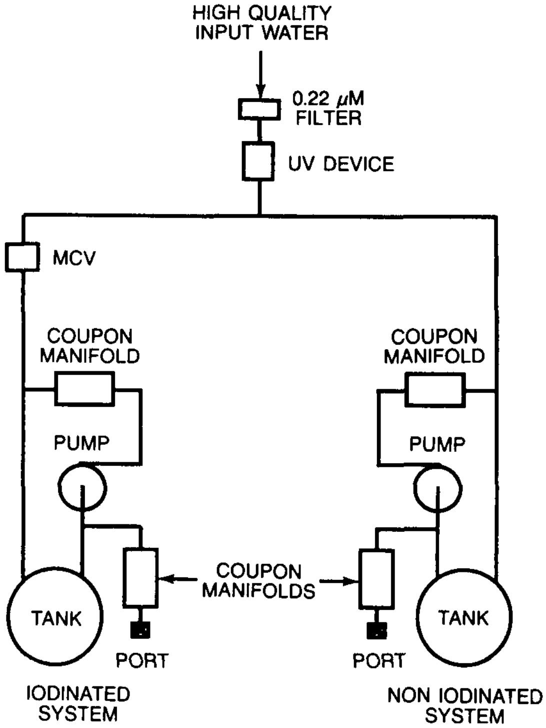
The JSC Water and Food Analysis Laboratory, with support from the JSC Microbiology Laboratory, has developed a test bed which simulates a spacecraft water system of a type which would support a long-duration flight. The present research effort has two primary objectives:

- Evaluation of iodine as an anti-microbial/anti-biofouling agent in such a system
- Evaluation of biofilm formation potential in this system over an extended (2-year) period of time.

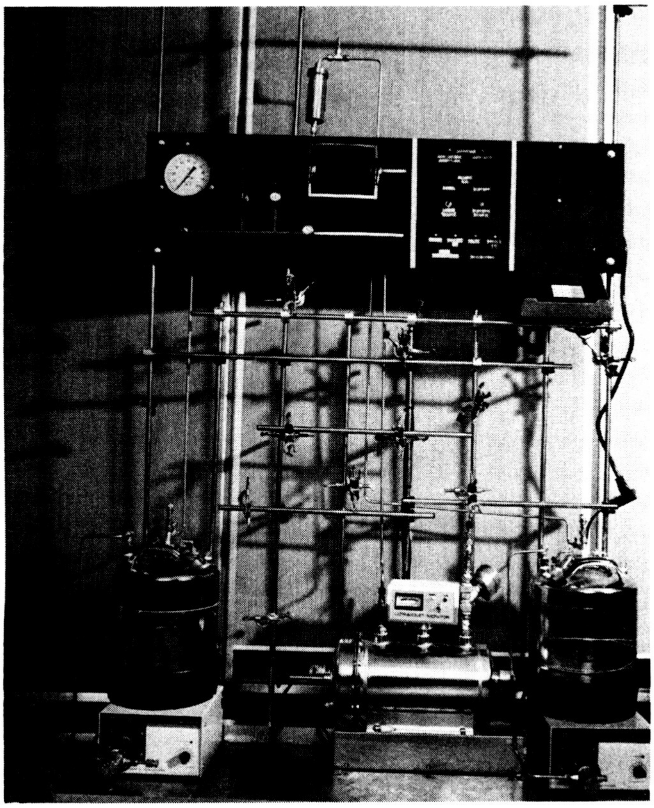
Secondary objectives are diverse and include comparison of biofilm formation on electropolished vs. non-electropolished surfaces, comparison of stainless steel corrosion rates and biofilm formation in iodinated vs. non-iodinated systems, and evaluation of sampling methodologies.

The test bed is divided into two parallel subsystems. Each consists of a 10-liter storage tank, a pump-driven recirculation loop, a distribution circuit, and manifolds containing test coupons. The test bed is supplied with high quality make-up water passed through a 0.2 um microbial filter and an ultraviolet disinfection device immediately prior to entry into the test bed. One of the test bed subsystems is iodinated at a level of about 2.5 mg/L by an iodinated ion-exchange resin; this resin is contained in an STS Orbiter Microbial Check Valve (MCV). The other subsystem loop has no iodine added. To simulate actual use by a two-member crew, 2-liter withdrawals are made from each of the subsystems every 8 hours. The quality of the water from each half of the test bed is monitored regularly; both chemical and microbiological tests are performed. Stainless steel biofilm test coupons, located in the recirculation loop and draw leg of each half of the system are used to monitor biofilm formation. These coupons are examined using bacteriological culture methods, epifluorescence microscopy, and scanning electron microscopy.

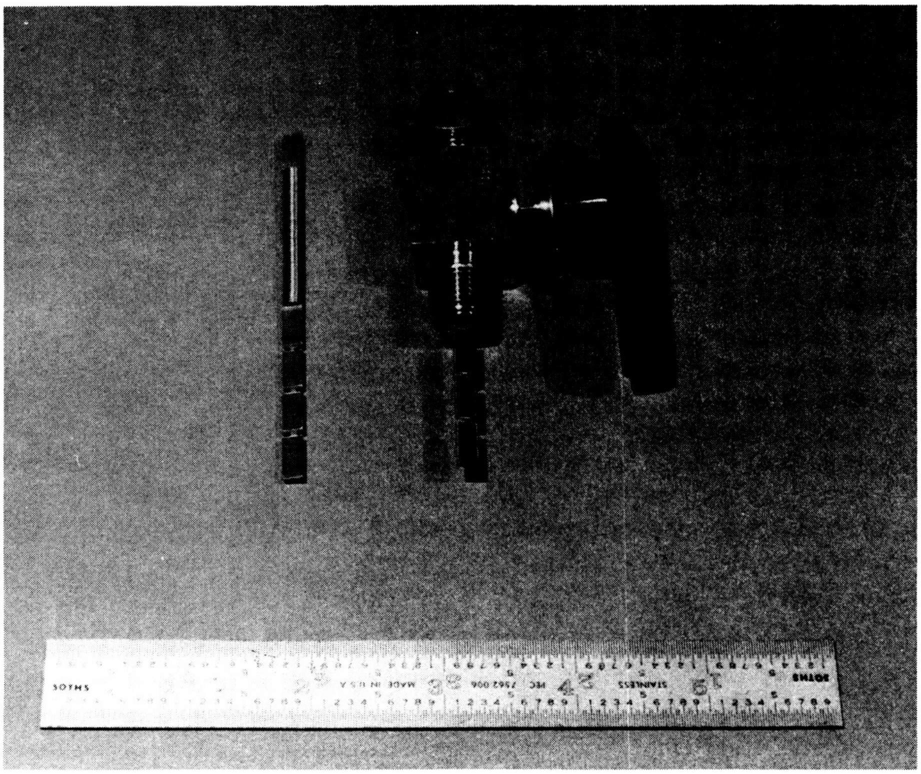
The experiment has a planned duration of 2 years; 6 months of experimental work has been completed. The iodine levels in use have thus far been successful in preventing the obvious presence of bacteria in the iodinated subsystem; the non-iodinated subsystem was revealed to be contaminated after only 3 weeks of operation. Total organic carbon levels of 50 to 100 ppb are found in both subsystems. Trace metal analyses indicate no significant corrosion of either subsystem has occurred. The average pH levels are 4.5 and 5.0 in the iodinated and non-iodinated subsystems, respectively. Ion chromatography reveals traces of nitrate, sulfate, and chloride. Phosphate levels are below the limits of detection which may imply that this nutrient is the growth-limiting nutrient for bacterial growth.




**Simplified schematic of water system designed to support long-duration space flight.**



**Functional water system test bed.**



**Stainless steel biofilm test coupons.**

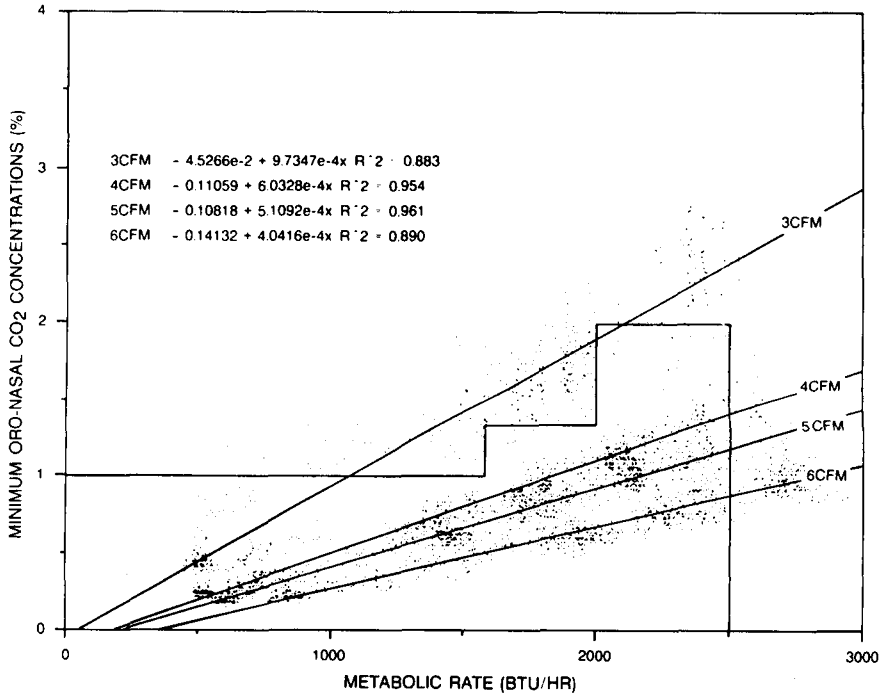
## Determination of Residual Carbon Dioxide During Forced Ventilation of a Hemispherical Spacesuit Helmet

**TM: James M. Waligora/SD5
David J. Horrigan, Jr./SD5
PI's: John H. Gilbert, III/KI-SD5
Susan Schentrup/EC3**
**Reference MS 15**

NASA is presently developing a new spacesuit which will allow extravehicular activities (EVA) of up to 6 hours. This 8.3 psia suit is designed to allow egress from Space Station Freedom without the necessity of 100 percent oxygen prebreathe procedures. The present Space Shuttle Suit is a 4.3 psia system and requires a prebreathe period to reduce the possibility of altitude decompression sickness. Since this new suit must withstand a larger pressure differential and because of the requirements of durability for space construction projects, this suit has undergone major configurational changes. It will be a hard upper torso suit with a hemispherical helmet. This hemispherical helmet design, with the greater freedom of head movement within it, creates the possibility of local areas of high carbon dioxide ($CO_2$) concentrations in poorly ventilated areas of the helmet. To reduce this potential hazard, a dual overhead vent configuration was designed, which creates a smooth downward laminar flow over most of the interior surface of the helmet. Experiments were conducted to verify the washout of $CO_2$ from all areas of the helmet, and to ascertain the flow rate(s) required to meet the NASA specifications for rebreathing of $CO_2$ in the helmet atmosphere.

Male and female volunteers were exercised on a treadmill in the new suit at metabolic rates (MR) varying from resting to 2500 BTU/hr (625 Cal/hr). Suit ventilation rates (VR) of 3 to 6 actual cubic feet per minute (ACFM) were tested. Measurements were made of oronasal $CO_2$ levels using a dedicated mass spectrometer. Continuous MR was determined using suit exhaust gases. All data were analyzed real time, presented on a computer monitor, and stored on hard disk.

Preliminary analysis of the data derived from 12 completed runs shows that $CO_2$ concentrations are statistically very different between the various flow rates. As would be expected, the 3 ACFM provided the least washout capability, but the large difference between the 3 and 4 ACFM measurements is unexpected. This difference, which is not seen between 4, 5, and 6 ACFM, may be attributed to the differential effect of the constriction on the mass flow of the gas at different back pressures of the flat, narrow overhead air vents in the helmet. However, the data show unequivocally that the 3 ACFM flow rate would not provide sufficient $CO_2$ washout in the helmet to meet NASA Medical Specifications. At present, it appears as if a single-speed fan system for the Portable Life Support System (PLSS) should probably be set at 5 ACFM to provide adequate helmet washout regardless of head position. However, in a two-speed PLSS system, a 4 ACFM speed would probably be acceptable for MR up to 1000, after which the system should use either 5 or 6 ACFM. However, as was mentioned above, the analysis of this data is preliminary, and further, more rigorous statistical measures are being applied to the data to verify these preliminary findings.




**Preliminary flow rate analysis, using medical $CO_2$ concentration restrictions.**

## In Vitro Three-Dimensional Tissue Modeling

TM: S. Gonda, Ph.D./SD4
PI: T. Goodwin, M.S./SD4;
J. M. Jessup, M.D./M.D. Anderson Tumor Institute;
C. Sams, Ph.D./SD4;
D. Wolf, M.D./SD4
Reference MS 16

Living organisms exist as a finely ordered architecture of cells and cell products. The removal of cells from this ordered environment typically alters their structure and function and may preclude their utilization for the production of cell products or for basic scientific study. A continuing challenge for tissue culture technology is to provide an environment adequate for survival of the cells, while maintaining the desired cellular characteristics expressed by the cells in the intact organism. To achieve this goal, cell culture procedures are designed to provide an environment which approximates that experienced by the cells within an animal. Growth factors, specialized cell attachment surfaces, and co-culture with additional cell types are all utilized for this purpose. An additional critical item is the spatial orientation of cells with regard to their attachment surface, nutrient supply, and other interacting cells. The spatial orientation of the cells within their environment may be the key to both understanding and controlling cell behavior in culture.

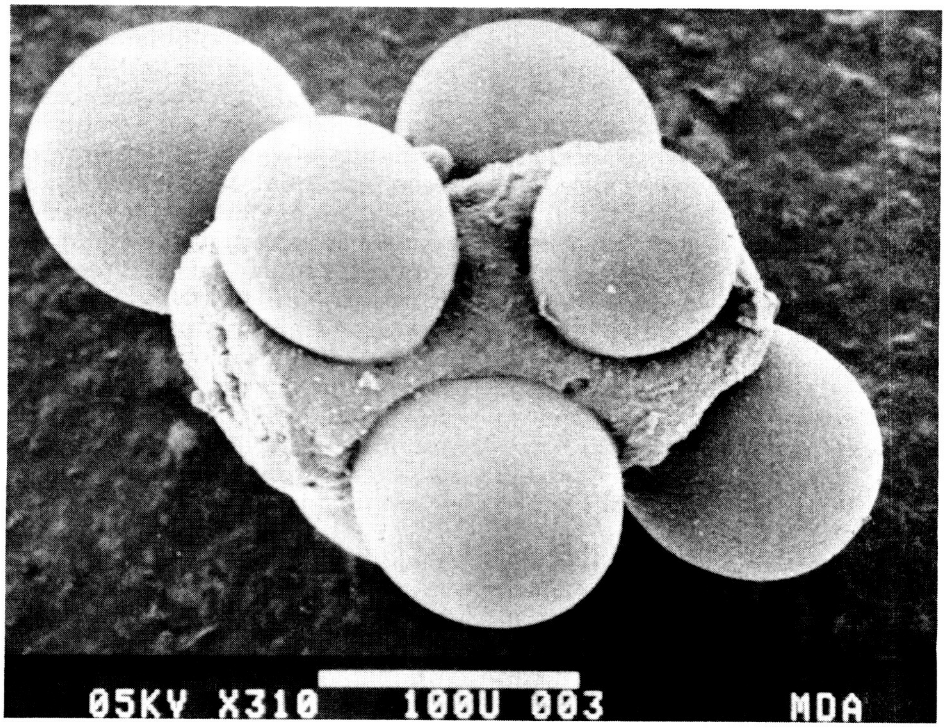
Research in progress at the Johnson Space Center is examining the application of three-dimensional cell culture techniques to the study of cell growth and differentiation. While the culture of cells as three-dimensional structures is not unknown, the technical limitations of this process are significant. Cultures are traditionally grown on flat culture plates, in semisolid medium or in stirred culture medium. The respective limitations of these techniques include two-dimensional growth constraints, reduced exchange of nutrients and waste products, and cellular stress induced by stirring. New cell culture systems designed in the JSC Biotechnology Laboratories for use in microgravity have been used to explore the utility of three-dimensional culture in liquid medium. The culture systems rotate a fluid-filled culture vessel about a horizontal axis, randomizing the gravity vector and suspending cells with a minimum of fluid shear. These systems provide three-dimensional freedom of cellular assembly without the nutrient transfer or fluid shear problems associated with traditional culture methods. The ability to grow and maintain viable "tissue-like" aggregates of cells provides the opportunity to investigate fundamental processes in cellular communication, organogenesis, and developmental biology. While these methods represent a significant advance in culture technology, the optimal culture environment cannot be maintained indefinitely in unit gravity. Operation in microgravity will be required to overcome the remaining gravity-induced limitations and should result in a significant increase in scientific return.

Initial experiments have focused on the growth and differentiation of two human adenocarcinoma cell lines (HT29 and HT29KM). These cells are attachment-dependent and require the inclusion of small beads (microcarrier beads) for growth. The tumor cells were cultured with and without fibroblasts which form the stromal or support layer for this cell type in the intact organism. Without the fibroblasts, the tumor cells grew as undifferentiated masses between the beads. When fibroblasts were included in the culture, the fibroblasts covered the bead surface, and subsequently, the tumor cells attached to the fibroblast layer and grew into cell masses exhibiting significantly increased differentiation. Three-dimensional assemblies were formed which contained structures resembling colon crypts or glands. In addition, cells exhibited unique staining characteristics not observed when the cell types were cultured individually. These data suggest the specific exchange of cellular signals between the fibroblasts and the tumor cells results in the expression of a more differentiated phenotype. The exact nature of the cellular signals regulating this process is unknown; however, these cell culture systems provide the means to investigate this phenomenon free of the complicating factors which would be encountered using an animal model.

Three-dimensional culture technologies hold a great deal of promise for advancing basic understanding of biological processes and for novel applications in the clinical and industrial setting. These could include:

- investigation of the fundamental processes regulating development of organs and tissues
- control of normal and neoplastic tissue growth and the factors controlling the invasion of normal tissue by cancerous cells
- use of biopsy cultures to test chemotherapy protocols to determine the most effective treatment for individual cancers
- expansion of cells and tissue for transplantation
- isolation of growth or regulatory factors from interacting cell systems

Such programs would be instrumental to the development of new procedures and therapeutics to fight disease, new industrial processes involving cultured animal cells, and improved scientific knowledge of the factors regulating cell growth and differentiation.




Scanning electron micrograph of HT29 cell mass between microcarrier beads. The microcarrier beads are the rounded structures attached to the outer surface of an unstructured mass of HT29 cells.


Scanning electron micrograph of a co-culture of HT29KM and normal colonic fibroblasts. A microcarrier bead is visible as the smooth spherical object in the upper left. The tumor cells have assembled into a three-dimensional architecture overlaying the fibroblast-covered beads. Numerous gland-like pores are visible.

## Flow Cytometric Analysis of Peptide Hormone Receptor Regulation on Circulating Human Monocytes and Lymphocytes

**TM:** Clarence Sams, Ph.D./SD4
**PI:** Richard Meehan, M.D./UTMB
Nitza Cintròn, Ph.D./SD4
Charles Stuart, M.D./UTMB
Laureen Neale, MS/SD4
Elizabeth Kraus/SD4
Morey Smith MS/UTMB
**Reference MS 17**

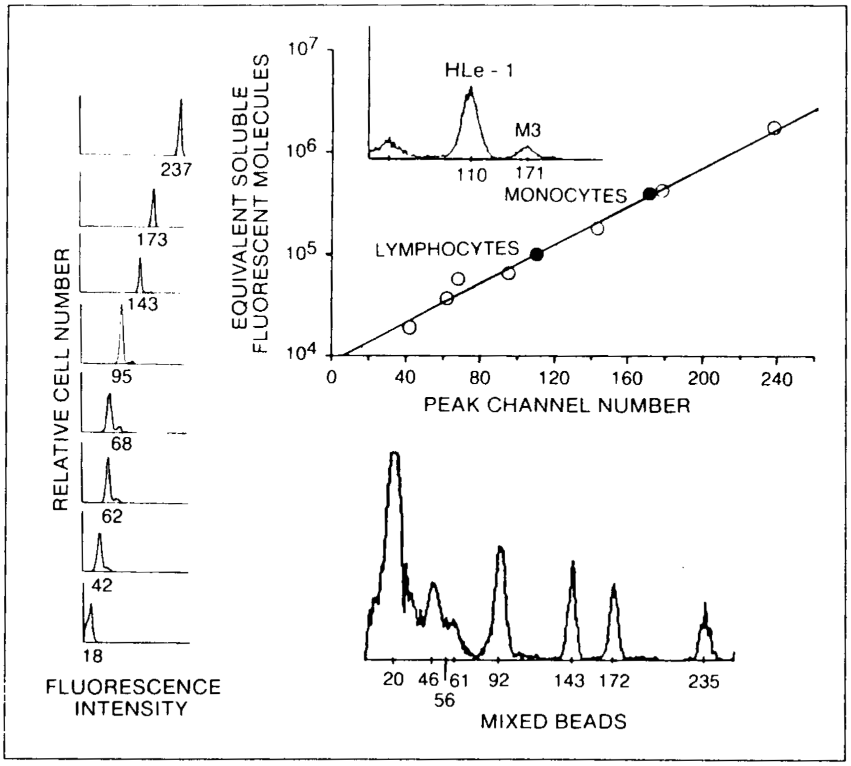
Examination of the factors regulating human physiological adaptation to space flight is critical to the continued expansion of manned exploration in space. It is, however, technically difficult to define the potential role of circulating hormones in the pathogenesis of space-flight-related maladies such as Space Adaptation Syndrome, musculoskeletal atrophy and immune suppression. A new method has been developed, utilizing immunofluorescence staining and flow cytometry, to noninvasively monitor endocrine responses at the cellular level and investigate mechanisms of space-flight-induced physiologic responses.

Circulating peripheral blood mononuclear cells (PBMNC) express functional receptors for a variety of peptide hormones, including insulin, insulin-like growth factors, ACTH and endorphins. The standard method for studying receptor regulation involves binding studies with radio-labeled ligands. Our new method of detecting and quantifying low-density hormone receptors on PBMNC offers a variety of specific advantages for life scientists who wish to investigate endocrine mechanisms given the operational constraints of space-flight-related investigation.

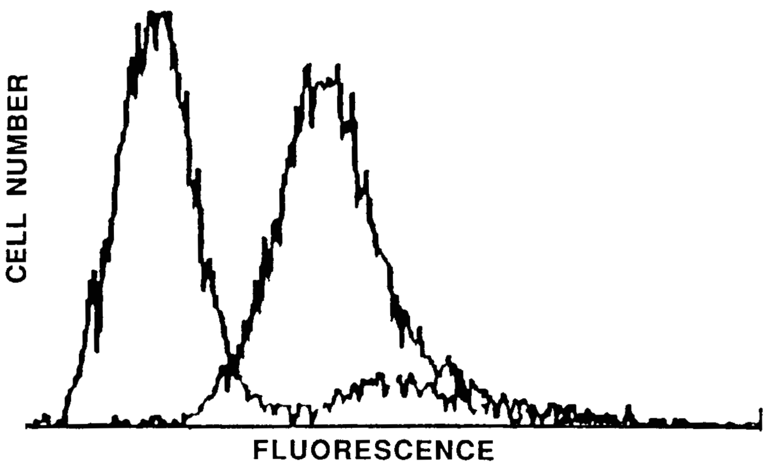
The advantages include:

- small volumes of blood are required
- isotopes are avoided
- there is a potential for non-invasively monitoring receptor expression on less accessible organs (CNS tissue and muscle)
- there is a potential for detecting chronically elevated or depressed circulating ligand levels or identifying cellular markers for immune or hematologic dysfunction
- cells can be fixed in- flight or post-flight to facilitate analysis
- this methodology will easily incorporate newer cellular probes as they become available from advances in molecular biology and biotechnology

Dual color flow cytometry analysis of immunofluorescence staining with monoclonal antibodies and immunoaffinity-purified antisera against these cell surface receptors has been employed to determine which subpopulations of circulating mononuclear cells express receptors. We have determined that during certain stressors, the percentage of human PBMNC which express these receptors per cell can be quantified by flow cytometry and immunofluorescence microscopy with digital image analysis. Pre-calibrated standard beads which vary in immunofluorescence intensity and beads coated with a known quantity of immunoglobin molecules (Flow Cytometry Standards, Inc.) are used to generate a standard curve of fluorescence intensity. We are able to obtain excellent agreement between the number of insulin receptors on IM9 (a lymphoblastoid cell line) cells determined by immunofluorescence and the corresponding values obtained from scatchard analysis of 125I-labeled insulin binding. It is now possible to identify and quantify up-or down-regulation of cell surface hormone receptors or molecules within mixed populations of PBMNC. This methodology has successfully been utilized to monitor insulin and IGF receptor expression on PBMNC from STS crewmembers following space flight. This technology holds great promise for noninvasively monitoring crew health or endocrine responses, detecting subtle physiologic responses at the cellular level or identifying perturbations which may be unique to microgravity conditions.




Graded fluorescence intensity is demonstrated on 8 separate standard beads. The fluore-scent intensity of cells stained with 2 cell surface markers, HLe-1 and $M_3$, are also plotted for comparison.




Fluorescence distribution histograms of IM9 cells stained with a control anti-body (left peak) and monoclonal anti-body against the insulin receptor (right peak).

## Gaseous Sterilization of Bioreactors

**TM: David A. Wolf, M. D./SD4**
**PI: John H. Cross, Ph.D./SD4**
**Ray P. Schwarz, B. Sc./SD4**
**Reference MS 18**

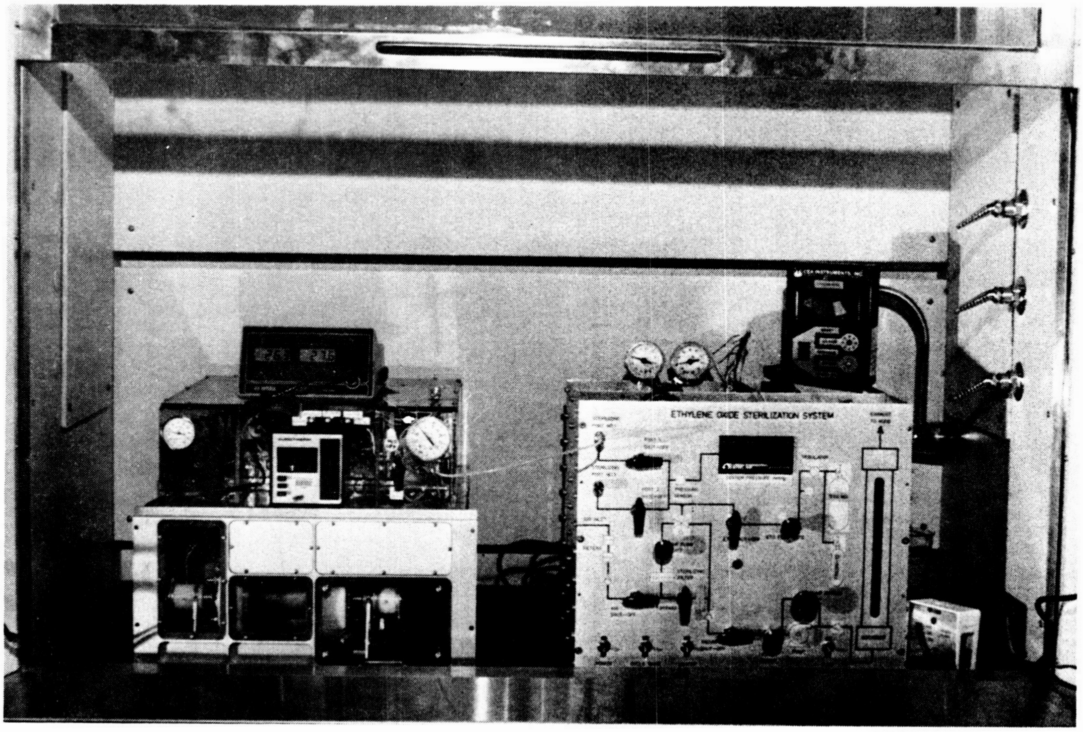
Bioreactors used in NASA's Biotechnology Program must meet special requirements to operate in the Space Shuttle and in microgravity (See JSC Research and Technology Report, 1987). Because these bioreactors are used to grow mammalian cells, they must be sterilized to prevent fast-growing bacteria from overwhelming the slow-growing mammalian cells. Steam sterilization in an autoclave could lead to binding and eventual failure of plastic parts rotating with close tolerances. This possibility was averted by developing a process for gaseous sterilization at mild temperatures.

Ethylene oxide (ETO) was chosen, because it is lethal to all microbes and their spores. The pure gas is, however, flammable. This problem is circumvented by diluting the ETO with a nonflammable gas. We selected a mixture widely used in hospital sterilizers, 10 percent ETO in halocarbon-12, because it provides sterilizing concentrations of ETO at low pressures. Preliminary tests established that ETO would sterilize the bioreactor materials and would leave only minor amounts of residuals toxic to mammalian cells. Early attempts at using ETO to sterilize bioreactors, complete with all their complex tubing for routing gases and liquids, in the gas sterilizer of a local hospital led to mixed results; the successful attempts had a tendency to correspond with longer sterilization times.

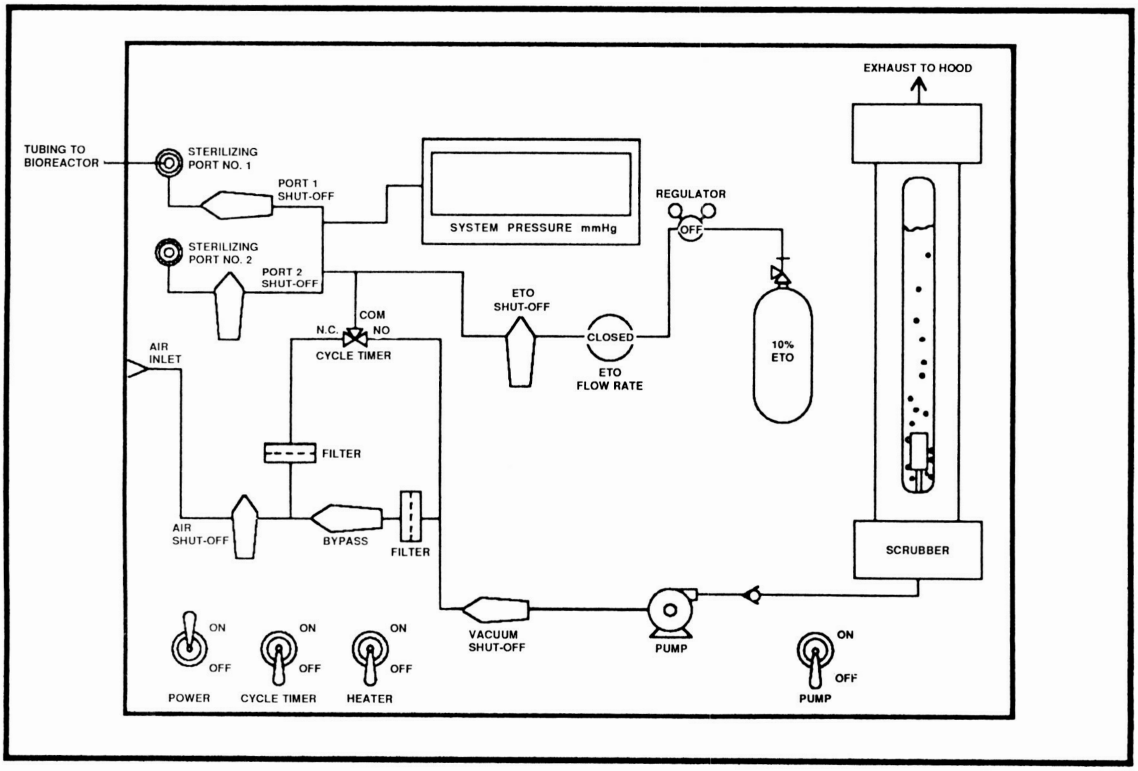
Analysis of these early attempts led to the key concept for a novel sterilization process. One element of the concept was the observation that when sterilization failed, the bacterial contamination would originate in sections of complex, inaccessible tubing. This suggested that sterilizing concentrations of ETO were not reaching all parts of the bioreactor. The other element of the concept arose from a constraint imposed by operating bioreactors in spacecraft. The atmosphere in the Space Shuttle is controlled but is not kept sterile. Scientists in the Biotechnology Program have developed suitable cell culture techniques that assume sterility ends at the exit ports of the bioreactor. Sterility of the outside of the bioreactor is, therefore, unnecessary. These two elements, taken together, suggest that a sterilization process could be developed along the lines of circulating ETO throughout the inside of a bioreactor.

This key concept has been reduced to practice. The specially-designed apparatus for use in this process has two units. The first delivers the pressure-regulated ETO mixture and removes it after use (see schematic). The second unit warms, humidifies, and circulates the mixture through the bioreactor. All pieces exposed to ETO are operated in a chemical fume hood. The process for sterilization initially follows the conventional one by alternately filling and evacuating the bioreactor until a sterilizing concentration of gas is reached. The novel features occur during a two-hour period when the gas remains in the bioreactor; the gas is continuously circulated, and the relative humidity is controlled between 30 and 50 percent. Any valves in the equipment are operated to ensure penetration by sterilizing gas. Gas circulates to all parts of the apparatus that must be sterile for cell culture. Other parts, such as electronic modules and controls, are not exposed. After the sterilizing period, the ETO mixture is removed by vacuum, and sterile air is admitted. This cycle is repeated at four-minute intervals for two hours or more. Finally, the bioreactor is washed with slightly acidic water overnight and then rinsed with neutral water. The process, taken as a whole, provides reliable sterilization with negligible residual ETO toxicity.

Other potential applications of this technique include sterilizing the mechanical parts of electromechanical medical equipment such as heart-lung machines and dialysis equipment. The crux of this application is to sterilize only those sections of an apparatus that must be free of microbes. Other sections are not exposed to an unnecessary treatment. Avoiding unnecessary treatment confers a particular advantage for equipment with electronic modules, because the catalytic decomposition of ETO by copper, found in many electronic modules, would create a hazard if the electronics module were exposed to ETO. Since the ETO is always contained, and exposure to ETO is easily minimized, another possible use is in applications where exposure to ETO must be reduced below even the stringent limit imposed by OSHA.




The sterilization apparatus. The delivery system is on the right. The humidifier and heater unit is the upper section of the left equipment stack. The lower unit is the bio-reactor culture vessel and fluid loop undergoing sterilization.



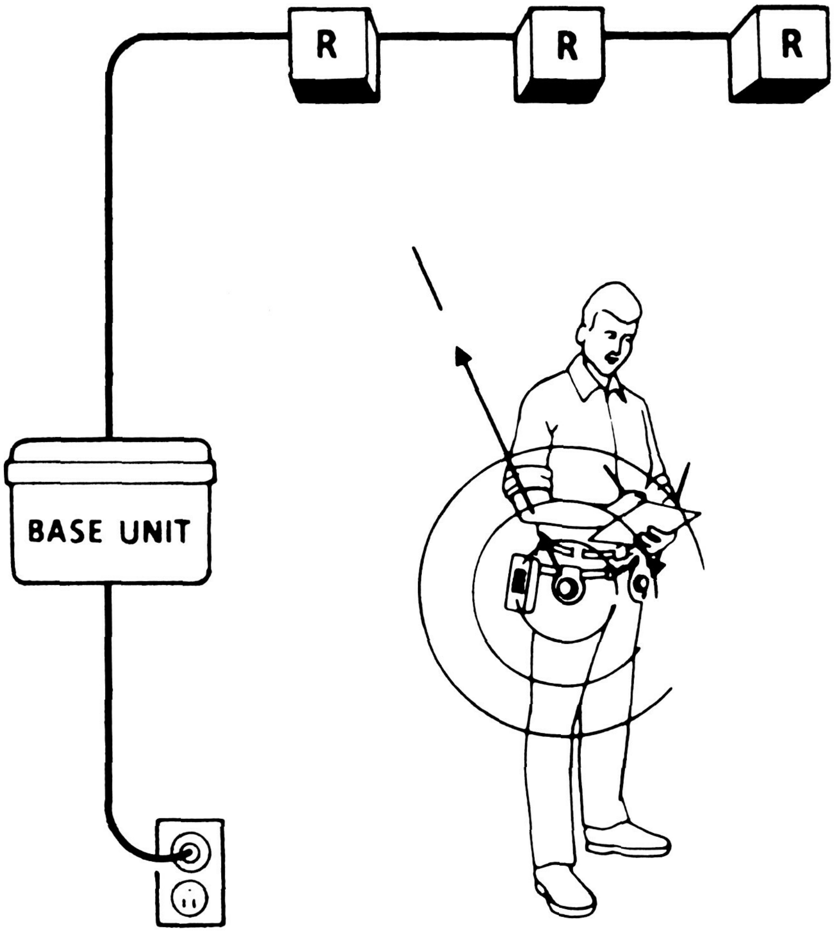

Schematic for the ETO delivery system.

## Infrared Physiological Data Link

**PI: K. F. Dekome/EE6**
**Reference MS 19**

The Infrared Physiological Data Link (IPDL) was developed as a nonintrusive means of monitoring important biomedical data such as electroencephalogram (EEG), electromyogram (EMG), electrocardiogram (ECG), and respiratory rate data. This system consists of a transmitting unit worn on a belt which digitally encodes the data and transmits it via infrared light to a remotely located receiving base unit. The infrared light being transmitted reflects off the walls and ceiling of the room and is collected by serially linked remote receivers attached around the perimeter of the room. The user has total freedom of movement within this perimeter, and is free from constraining umbilicals. Development of the current system was completed this year with prior-year funding. The system can support eight channels of analog data of 300-Hz bandwidth each, along with two digital input channels of 10 kbps each (9600 baud serial data). The data can be read from the base unit either as received digital data or as reconstructed analog waveforms. The transmitting unit uses a rechargeable nickel-cadmium battery cartridge capable of up to eight hours usage between charges.

This hardware design is being incorporated into new hardware being developed by the Life Sciences and Man-Systems Divisions for use on Spacelab and Space Station Freedom.




**IPDL concept.**

## Medical Considerations in the Design of a Crew Emergency Return Vehicle

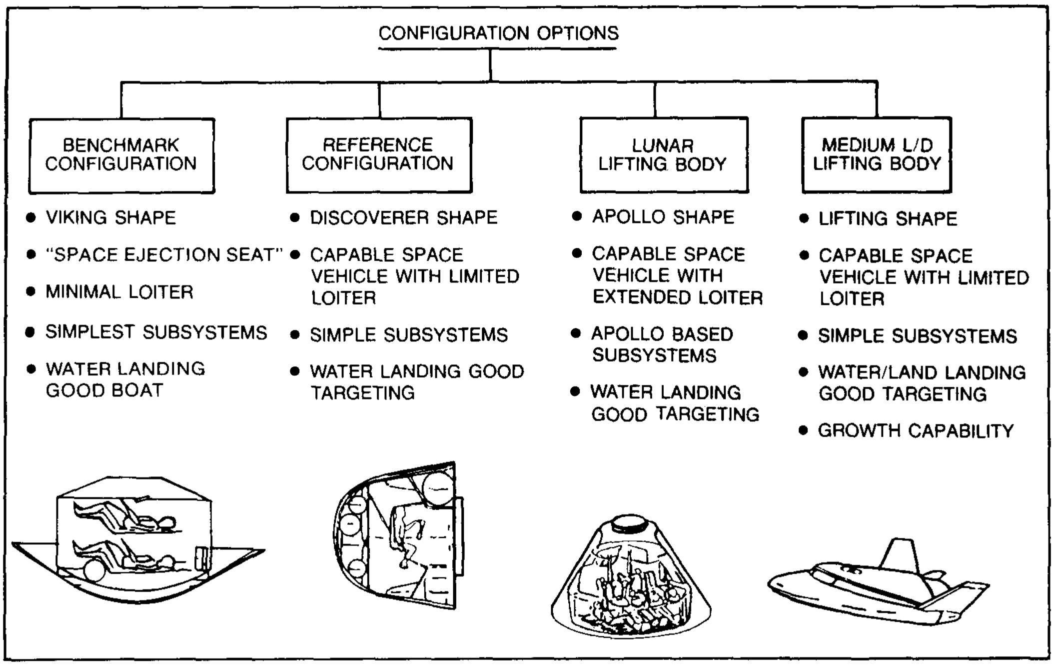
**PI: J. Boyce, M.D.**
**Reference MS 20**

Medical illnesses or injuries that may occur on Space Station Freedom may exceed the capabilities of the planned Health Maintenance Facility and necessitate medical transport or evacuation of one or more crewmembers. However, the benefits of transporting a crewmember in the proposed Crew Emergency Return Vehicle (CERV) to a definitive care facility must be weighed against risks and costs of transport and deorbit. A multitude of factors, including criteria for transport, predicted incidence of medical transport, effects of deorbit accelerations on an ill/injured patient, rescue and recovery of the CERV must be considered in order to make appropriate decisions on crew safety in the Space Station Freedom era.

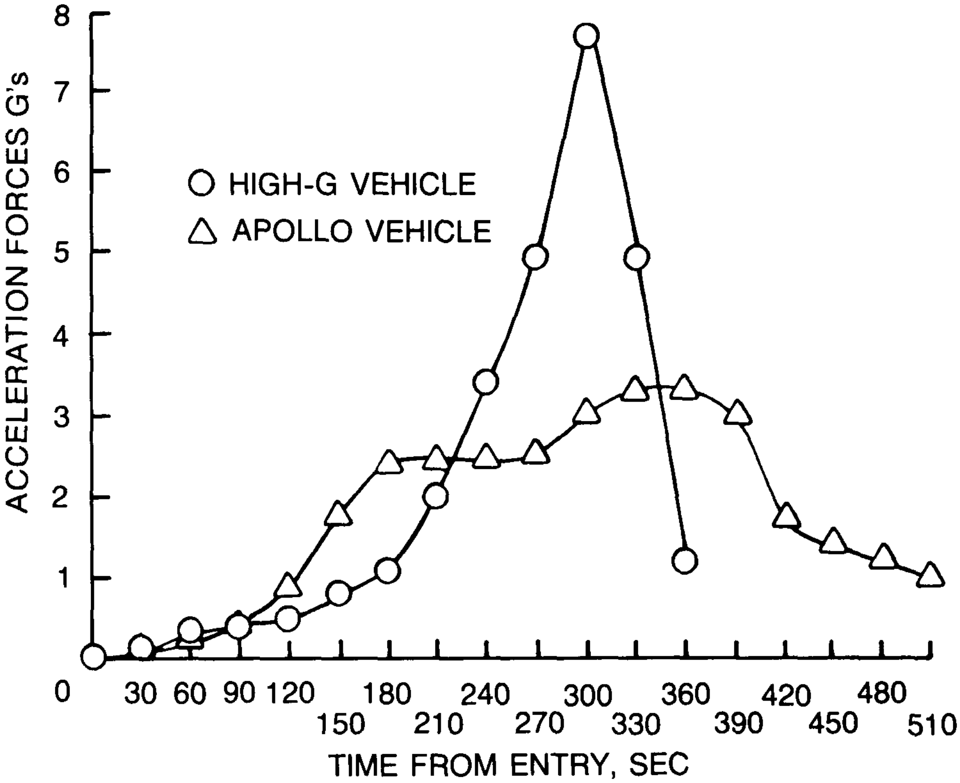
The SD2 Medical Operations Branch of JSC, working in collaboration with principal investigator Dr. Glenn Hamilton and his team at Wright State University (WSU), Dayton, Ohio, and Dr. Alan Hargens and his group at Ames Research Center and the University of California Davis, are investigating these areas in a multifaceted research effort that will allow more accurate decision-making for CERV design and operation. The WSU study effort will focus mainly on two areas: 1) the general considerations for Medical Rescue from the Space Station, and 2) the effects of entry gx forces on a hemorrhagic shock patient model. The Ames/UC Davis study will further investigate the effects of entry gx forces on cardiopulmonary injury models to determine the risks of using a CERV for transport of a critically ill patient.

These studies will help determine CERV systems requirements, medical equipment design and interfaces, safety of CERV use, indications for medical transport, transport treatment protocols, risks and complications of transport, search and rescue force requirements, transport team requirements, and other issues for CERV medical transport. A preliminary driver in early vehicle design considerations is the potential requirement to limit acceleration forces of entry on the ill crewmember. In some simple vehicle designs, entry forces in the +gx axis (eyes in) may be as high 8g's, which can be painful even for healthy crewmembers. Designs which utilize lifting forces to lessen the entry accelerations and spread them out over time may have accelerations of 4g down to the 1.7g of the Space Shuttle. Potential vehicle designs and the entry profiles for two example vehicle designs are shown for comparison in the figures.

Experimental data was lacking to determine the effects of these forces on an injured or ill patient. By modeling the most likely (and most affected by gx) illnesses and determining the actual effects of the entry forces on vital patient parameters, the requirements for a low vs. a high g CERV were determined, and a new body of information was developed. Understanding these previously unanswered questions will be essential to future space flight medical support and safety of NASA Space Station Freedom crewmembers.




**Concept studies for crew emergency return vehicle.**




**Crew rescue vehicle - Apollo and high-g vehicle reentry profiles.**

## Mode A Preflight Adaptation Trainer

TM: Deborah L. Harm, PH.D., SD5
PI: Donald E. Parker, PH.D, Miami University
Reference MS 21

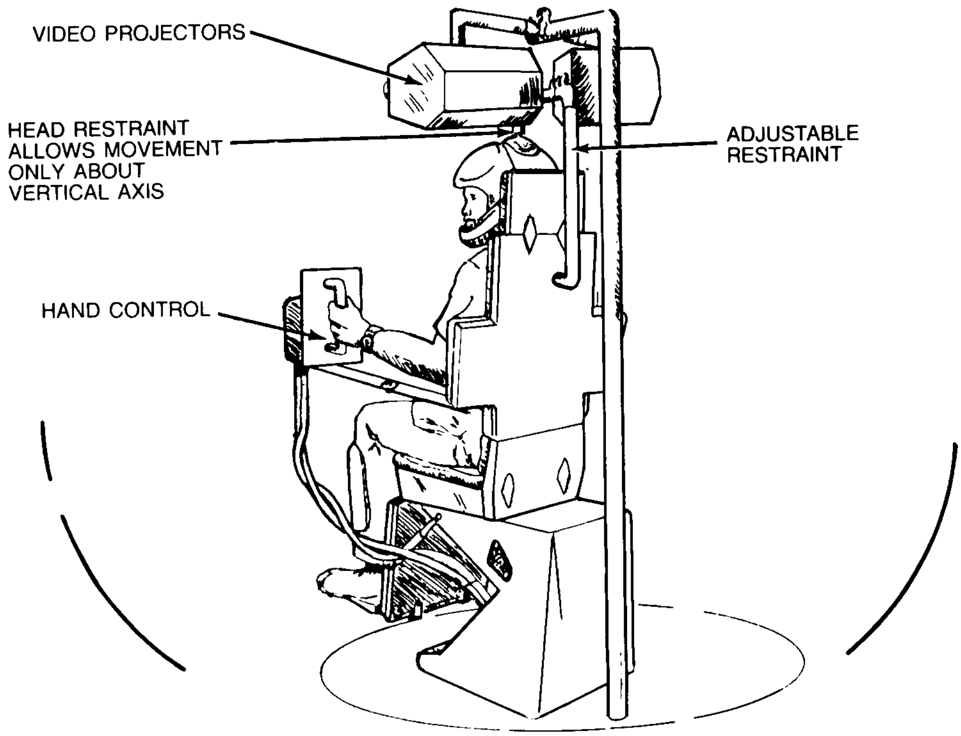
A series of trainers/simulators for preadapting astronauts to some of the sensory rearrangements experienced in spaceflight are being developed at NASA/JSC. The absence of gravity in space alters the relationships among sensory inputs, and the resultant sensory conflict is largely responsible for space motion sickness (SMS). Preflight adaptation training in altered sensory environments should help reduce or eliminate SMS.

The most sophisticated of these trainers is the Mode A Preflight Adaptation Trainer (PAT). This PAT will have a dome-like enclosure for the astronaut trainee. The enclosure will also serve as the projection surface for video images produced by a computer. By using multiple video projectors, all connected to the same computer, a display with a very wide-angle field of view can be presented to the trainee. Utilizing recent advances in relatively low-cost computer image synthesis hardware, the images presented can be the interior of a variety of surroundings. The visual scenes can represent the inside of the Space Shuttle and Spacelab, Space Station Freedom, or an artificial environment, such as a series of interconnected rooms.

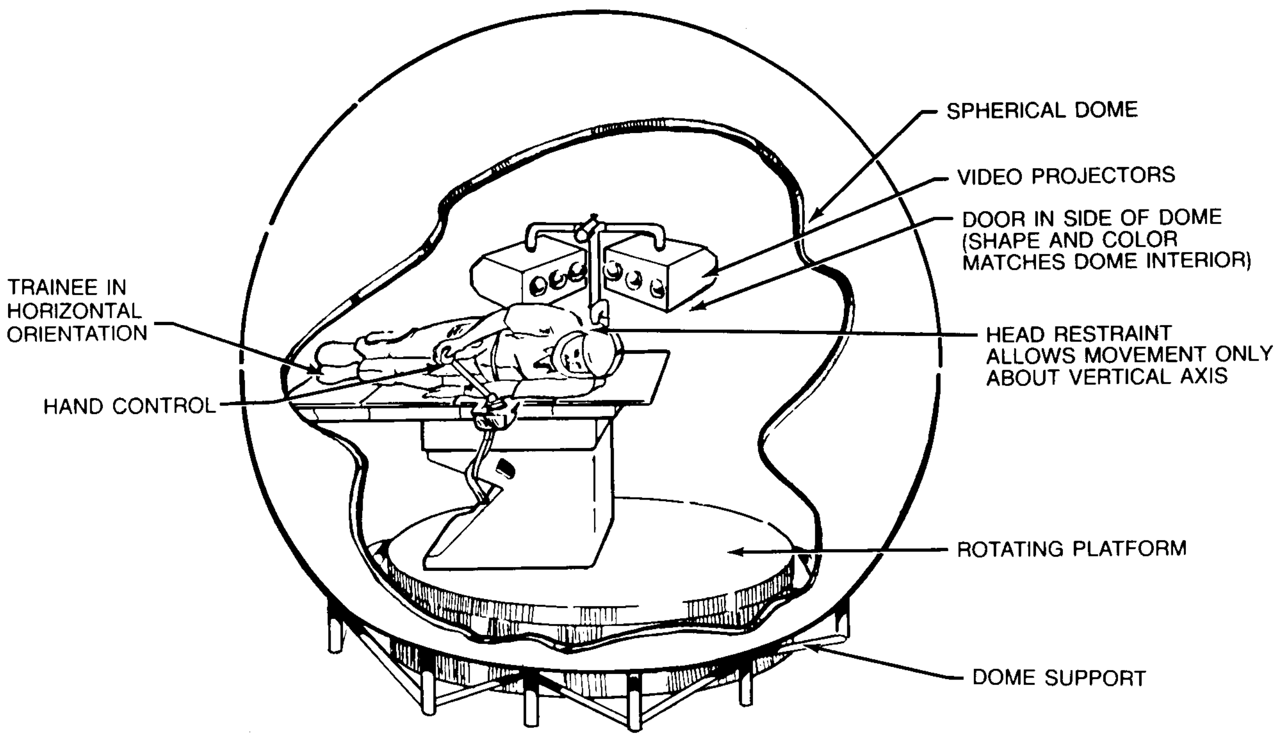
Trainee-generated input comands to hand and/or head controls will enable him/her to visually move around inside the virtual environment displayed by the projectors. This will simulate moving around inside the spacecraft in microgravity. The astronaut will be able to push on the hand control surface in a manner similar to pushing away from a bulkhead, this will cause the visual surroundings to move away, as it would appear while in orbit.

A key aspect of this PAT is the absence of tilt information from gravity to the trainee. In an Earth-gravitational field, tilting head and body movements are associated with corresponding sensory information from the vestibular organs in the inner ear. These organs sense angular and linear movements and the tilt angle with respect to gravity. The vestibular structures that sense angular acceleration operate essentially the same way on Earth and in microgravity. However, the structures that sense linear acceleration and tilt angle with respect to gravity (otoliths) cannot provide tilt angle information to the astronaut in space. Loss of this information results in a conflict between visual and vestibular senses. Sensory conflict is one of the primary reasons why astronauts experience SMS. Sensory rearrangements produced by the absence of the gravity vector can be simulated in the Mode A PAT by not allowing head movements except about a vertical axis. Virtual movements of the computer-synthesized scenes will be allowed in any direction, with rotation about any axis, so that the astronauts can learn to become comfortable with changing orientations inside a simulated spacecraft or other surroundings without the normal tilt cues.

Training in this PAT should allow the astronauts to reduce their adaptation times in orbit and to avoid the most unpleasant symptoms of SMS, associated with adaptation to microgravity.




Mode A PAT, showing the trainee restrained and oriented in the upright position inside the dome. The projection system is mounted on the chair, and the chair is mounted on a rotating platform.




Mode A PAT, showing the trainee restrained and oriented in the hori-zontal position inside the dome. The trainee can be positioned either on his side or supine.

# Index

# Index

NAS9-17900

**SST 10** **Full Color AC Plasma Panel Display**
Funded by: Small Business Innovation Research (UPN 324)
Principal Investigator: A. J. Farkas/EF2
Task Performed by: Photonics Technology, NAS9-17948

**SST 11** **Helmet-mounted Display Human Factors**
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigator: Barbara Woolford/SP3
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900

**SST 12** **Hierarchical Three-Dimensional and Doppler Imaging Lidar**
Funded by: Small Business Innovation Research (UPN 324)
Principal Investigator: K. F. Dekome/EE6
Task Performed by: Autonomous Technologies, NAS9-17934

**SST 13** **Programmable Remapper**
Funded by: Technology Utilization (UPN 141)
Principal Investigator: T. E. Fisher/EE6
Task Performed by: Texas Instruments, NAS9-17201

**SST 14** **Optical Processing**
Funded by: Utilization (UPN 141)
Principal Investigator: R. D. Juday/EE6
Task Performed by: Texas Instruments, NAS9-17201
Lockheed Engineering and Science Co., NAS9-17900

**SST 15** **Development of a Hygiene Waste Water Filter**
Funded by: Small Business Innovation Research (UPN 324)
Principal Investigator: Rafael Garcia/SP4
Task Performed by: Johnson Space Center Umpqua Research Co., NAS9-17996

**SST 16** **Development of an Air/Liquid Separator for Hair Cleansing in Microgravity**
Funded by: OSF Optional Services (UPN 928)
Principal Investigator: Rafael Garcia/SP4
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900
Subcontract to Garrett Airsearch

**SST 17** **Electronic Still Camera Project**
Funded by: Space Station (UPN 472)
Principal Investigator: H. D. Yeates/SP43
Task Performed by: Johnson Space Center

**SST 18** **Space Station Material Evaluation Studies**
Funded by: Space Research and Technology Base (UPN 506); Space Station (UPN 472)
Principal Investigator: James T. Visentine/EG5
Task performed by: Los Alamos National Laboratory, T-4726P

| | |
|---|---|
| SST 19 | **In-flight Evaluation of the Structural Integrity of Spacecraft**<br>Funded by: Space Research and Technology Base (UPN 506)<br>Principal Investigator: John Sunkel/EH2<br>Task Performed by: Charles Stark Draper Laboratory, NAS9-17560<br>Subcontract to University of Lowell, Ma. |
| SST 20 | **Long-reach Retrieval Latch System**<br>Funded by: Space Station (UPN 472)<br>Principal Investigator: Peter M. Fantasia/ES6<br>Task Performed by: Johnson Space Center |
| SST 21 | **Electronically Variable Pressure Regulator**<br>Funded by: OSF Advanced Programs (UPN 906)<br>Principal Investigator: Eric Hurlbert/EP4<br>Task Performed by: Eaton Consolidated Controls, NAS9-17907 |
| SST 22 | **Laser Orientation Transceiver System**<br>Funded by: Small Business Innovation Research (UPN 324)<br>Principal Investigator: R. E. Juday/EE6<br>Task Performed by: Applied Research, NAS9-17930 |
| SST 23 | **Tunable Laser Diode and Optical Phase-Locked Loop**<br>Funded by: Small Business Innovation Research (UPN 324)<br>Principal Investigator: K. F. Dekome/EE6<br>Task Performed by: E-Tek Dynamics, NAS9-17992 |
| SST 24 | **Space Station Fiber Optics IF Distribution Breadboard**<br>Funded by: Space Station (UPN 472)<br>Principal Investigator: N. A. Olson/EE3<br>Task Performed by: E-Systems, Inc., NAS9-18008 |
| SST 25 | **Space Station's Near Field Antenna Test Facility**<br>Funded by: Space Station (UPN 472)<br>Principal Investigator: J. Ngo/EE3<br>Task Performed by: Johnson Space Center |
| SST 26 | **Control Zone Antenna System**<br>Funded by: Space Station (UPN 482)<br>Principal Investigator: J. S. Kelly/EE3<br>Task Performed by: Harris Corp., NAS9-17472 |
| SST 27 | **Extravehicular Mobility Unit Backpack Antenna System**<br>Funded by: Dicretionary Fund (UPN 307)<br>Principal Investigator: J. Ngo/EE3<br>Task Performed by: Johnson Space Center<br>Lockheed Engineering and Sciences Co., NAS9-17900 |
| SST 28 | **Preliminary CERV Antenna Analysis**<br>Funded by: OSF Advanced Programs (UPN 906)<br>Principal Investigator: J. A. Cook/EE3<br>Task Performed by: Lockheed Engineering and Science Co., NAS9-17900 |
| SST 29 | **Implementation of a Facility for Integrated System Testing Using Artificial Intelligence Techniques**<br>Funded by: Small Business Innovation Research (UPN 324) |

Principal Investigator: Henry S. Chen/EE8
Task Performed by: Stanford Telecommunications, Inc., NAS9-17607

SST 30 **Algorithm Development of the Coordinated Control of a Payload Utilizing Multiple Manipulator Arms**
Funded by: Small Business Innovation Research (UPN 324)
Principal Investigator: Gerald J. Reuter/EF2
Task Performed by: Oedticis, NAS9-17804

SST 31 **Thermal Expert System Integration**
Funded by: Space Research and Technology Base (UPN 506)
Technical Monitor: Thomas Pendleton/EF5
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900

SST 32 **CONFIG Tool: Qualitative Models and Discrete Event Simulation for Failure Analysis and Fault Management**
Principal Investigator: Jane T. Malin/EF5
Task performed by: Mitre Corp., F19628-86-C-0001

SST 33 **Human Interface with Intelligent Fault Management Systems**
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigator: Jane T. Malin/EF5
Task Performed by: Mitre Corp., F19628-86-C-0001
Univ. of Illinois, NAG9-137
Univ. of Michigan, NAG-139,
Intellicorp, NAS9-17686

SST 34 **Research at the JSC/UHCL Software Engineering Research Center**
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigators: S. A. Gorman/FR3; C. W. McKay
Task Performed by: Univ. of Houston at Clear Lake, NCC9-16

SST 35 **CFD Simulation of Shuttle Orbiter Entry Flow**
Funded by: Space Shuttle (UPN 583)
Principal Investigator: Chien-Peng Li/ED3
Task Performed by: Johnson Space Center

SST 36 **Infrared Communications Flight Demonstration**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: J. L. Prather/EE6
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900

SST 37 **Optical Communications Through the Shuttle Window**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: J. L. Grady
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900

SST 38 **Space Station Fluid Quantity Gaging**
Funding by: Space Station (UPN 481)
Principal Investigator: Kenneth R. Kroll/EP4
Task Performed by: Ball Aerospace Systems Division, NAS9-17616

SST 39 **Aeroassist Flight Experiment Flow Simulation Development**
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigator: Chien-Peng Li/ED3
Task Performed by: Johnson Space Center
Lockheed Engineering and Science Co., NAS9-17900

SST 40 **Catalytic Surface Effects Experiment**
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigator: R. Richard/ID3; D. Stewart/LaRc
Task Performed by: Rockwell International, NAS9-14000

SST 41 **Toughened Uni-Piece Fibrous Insulation**
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigator: R. Richard/ID3; D. Leiser/ARC
Task Performed by: Rockwell International, NAS9-14000

SST 42 **Base Flow and Heating Experiment**
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigators: Carl D. Scott/ED3; Michael C. Jansen/ED3
Task Performed by: Johnson Space Center
Lockheed Engineering and Science Co., NAS9-17900
Langley Research Center
University of Texas at Dallas

## SOLAR SYSTEM SCIENCES

SSS 1 **Experimental Geochemical Studies Related to the Chronology of Iron Meteorites**
Funded by: Planetary Materials (UPN 152)
Principal Investigator: John H. Jones
Task Performed by: Johnson Space Center

SSS 2 **A Unique Antarctic Meteorite: Possible New Clues to the Early History of the Solar System**
Funded by: Planetary Materials (UPN 152)
Principal Investigator: Gordon McKay/SN2
Task Performed by: Johnson Space Center

SSS 3 **Geochemical and Petrologic Studies of Planetary Differentiation on the Moon and Meteorite Parent Bodies**
Funded by: Planetary Materials (UPN 152)
Principal Investigator: Marilyn M. Lindstrom/SN2
Task Performed by: Johnson Space Center
Lockheed Engineering and Science Co., NAS9-17900

SSS 4 **Lunar Base Agriculture: Soils for Plant Growth**
Funded by: Life Sciences (UPN 199)
Principal Investigators: Don Henninger/SN14; Doug Ming/SN14
Task Performed by: Johnson Space Center

SSS 5 **Discovery of Sodium and Potassium Vapor in the Atmosphere of the Moon**
Funded by: Planetary Astronomy (UPN 196)
Principal Investigator: Andrew E. Potter/SN
Task Performed by: Johnson Space Center

SSS 6 **How Crowded is Space? Measuring the Amount of Extraterrestrial Material Falling to Earth**
Funded by: Planetary Astronomy (UPN 196)
Principal Investigator: Michael Zolensky/SN2
Task Performed by: Johnson Space Center

SSS 7 **Age Dating of Mesosiderites: Evidence for Major Parent Body Disruption Less than Four Billion Years Ago**
Funded by: Planetary Materials (UPN 152)
Principal Investigator: Donald Bogard/SN2
Task Performed by: Johnson Space Center

**SPACE TRANSPORTATION TECHNOLOGY**

STT 1 **Shuttle Performance Enhancement Using an Uprated OMS Engine**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigators: W. Boyd/ED2; C. Mallini/ED2
Task Performed by: Johnson Space Center

STT 2 **Uprated OMS Engine for Upper Stages**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigators: W. Boyd/ED2
Task Performed by: Aerojet Techsystems Co., NAS9-17215

STT 3 **On-Orbit Compressor Technology Program**
Funded by: Space Station (UPN 482)
Principal Investigator: John P. Masetta/EP4
Task Performed by: Southwest Research Institute, NAS9-18051

SST 4 **A Conceptual Design of a Personnel Carrier Shuttle II**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigators: W. Peterson/ED2; K. Templin/ED2
Task Performed by: Lockheed Engineering and Service Co., NAS9-17900

STT 5 **SCRAM--Conceptual Design Study**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigators: W. Peterson/ED2; K. Templin/ED2
Task Performed by: Lockheed Engineering and Service Co., NAS9-17900

STT 6 **Orbital Debris Studies**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: Donald Kessler/SN3
Task Performed by: Johnson Space Center
Lockheed Engineering and Science Co., NAS9-17900

STT 7 **Orbital Debris Control**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: Andrew J. Petro/ED2
Task Performed by: Johnson Space Center
Lockheed Engineering and Science Co., NAS9-17900

**STT 8** **Robotic Vision/Tracking Sensors**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: D. E. Rhoades/EE6
Task Performed by: Johnson Space Center
McDonnell Douglas Technical Services Co., NAS9-18200
Lockheed Engineering and Science Co., NAS9-17900

**STT 9** **Superfluid Helium Tanker**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: William C. Boyd/EP4
Task Performed by: Ball Aerospace Systems Division, NAS9-17852
Lockheed Missiles and Space Co., NAS9-17853
Martin Marietta Corp., NAS9-17854

**STT 10** **Superfluid Helium Orbital Resupply Coupling**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: William C. Boyd/EP4
Task Performed by: Ball Aerospace, NAS9-18021
Moog Space Products, NAS9-17872

**STT 11** **Satellite Services System**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: Charles T. Woolley/IB

**STT 12** **Lunar and Mars Exploration Study**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: Mark Craig/IZ
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900

**STT 13** **Lunar Base Systems Study**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: John Alred/ED2
Task Performed by: Eagle Engineering NAS9-17878

**STT 14** **Landing Analysis for Mars Sample Return Mission**
Funded by: Space Research and Technology Base (UPN 506)
Principal Investigator: Gene McSwain/EH2
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900
Charles Stark Draper Laboratory, NAS9-17560

**STT 15** **Mars Rover Sample Return Studies**
Funded by: Office of Exploration (UPN 906)
Principal Investigator: H. A. Nitschke/EE6
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900

**STT 16** **Intelligent Computer Aided Training**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: Robert T. Savely/FM7
Task Performed by: McDonnell Couglas Space Systems Co., NSA9-17885
Subcontracts to Lincom Corp. and CSC

STT 17 **Advanced Software Development Workstation**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: Robert T. Savely/FM7
Task Performed by: UHCLC, NAS9-16 with Subcontract to Inference Corp.

STT 18 **Integrated Autonomous Flight Operations Functional Simulation**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: C. J. Gott/FM7
Task Performed by: McDonnell Douglas Space Systems Co., NSA9-17885

STT 19 **Expert Systems Applications to Onboard Systems Management**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: Robert T. Savely/FM7
Task Performed by: McDonnell Douglas Space Systems Co., NSA9-17885

STT 20 **Autonomous Ascent Guidance Development**
Funded by: OSF Advanced Programs (UPN 906)
Principal Investigator: Dave Long/FM4
Task Performed by: McDonnell Douglas Space Systems Co., NSA9-17885

## MEDICAL SCIENCES

MS 1 **The Fluid Therapy System for the Space Station Freedom Health Maintenance Facility**
Funded by: Life Sciences (UPN 199)
Principal Investigator: Gerald J. Creager/SD12
Task Performed by: Krug International, NAS9-17720

MS 2 **Electronic Stethoscope for the Health Maintenance Facility**
Funded by: Life Sciences (UPN 199)
Principal Investigator: John W. Gosbee/SD12
Task Performed by: Krug International, NAS9-17720

MS 3 **Microgravity Air-fluid Separator for Space Station Freedom Health Maintenance Facility**
Funded by: Life Sciences (UPN 199)
Principal Investigator: Bruce Houtchens/Univ of Texas Health Science Center
Task Performed by: Krug International, NAS9-17720

MS 4 **Dental Diagnosis and Treatment for the Space Station Freedom Health Maintenance Facility**
Funded by: Life Sciences (UPN 199)
Principal Investigator: John W. Gosbee/SD12
Task Performed by: Krug International, NAS9-17720

MS 5 **Clinical Chemistry Analyzer for the Space Station Freedom Health Maintenance Facility**
Funded by: Life Sciences (UPN 199)
Principal Investigators: B. McKinley/SD12;
R. Jakubowicz/Eastman Kodak
A. Tonnesen/Univ. of Texas Health Science Center
Task Performed by: Krug International, NAS9-17720

MS 6 **Maintaining a Sterile Field and Sterile Technique in Microgravity**
Funded by: Life Sciences (UPN 199)
Principal Investigator: Katherine McCuaig/Univ of Alberta, Alberta, Canada
Task Performed by: Krug International, NAS9-17720

MS 7 **Zero Gravity Eye-Wash**
Funded by: Space Shuttle Program (UPN 568)
Principal Investigator: John M. Schultz/SD2
Task Performed by: Johnson Space Center

MS 8 **Operational Toxicology Database for the National Space Transportation System**
Funded by: Space Shuttle Program (UPN 568)
Principal Investigator: John M. Schultz/SD2
Task Performed by: Johnson Space Center
Krug International, NAS9-17720

MS 9 **Medical Operations Medical Records Database System**
Funded by: Space Shuttle Program (UPN 568)
Principal Investigators: Jeffery Davis/SD2; Sam Pool/SD
Task Performed by: Johnson Space Center
Krug International, NAS9-17720

MS 10 **Exercise as a Countermeasure for Microgravity-induced Deconditioning**
Funded by: Life Sciences (UPN 199)
Principal Investigators: Steven F. Siconolfi/SD5; Bernard A. Harris, Jr./SD5
Task Performed by: Krug International, NAS9-17720
Lockheed Engineering and Science Co., NAS9-17900

MS 11 **Space Station Freedom Exercise Countermeasure Facility Knowledge Based System for Monitoring Non-Invasive Physiological Data and Advising Exercise Countermeasures**
Funded by: Life Sciences (UPN 199)
Principal Investigator: Laurie Webster/EF5
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900

MS 12 **Halon 1301 Human Inhalation Exposure Study: Study Overview and Toxicokinetic Evaluation of Halon 1301 in the Exposed Subjects**
Funded by: Life Sciences (UPN 199)
Principal Investigators: Chiu-wing Lam/SD4; Theodore J. Galen/SD4; Duane L. Pierson/SD4
Task Performed by: Johnson Space Center
Krug International, NAS9-17720

MS 13 **Universal Sample Inlet System for Gas Chromatography-Mass Spectrometer Systems**
Funded by: Life Sciences (UPN 199)
Principal Investigators: Theodore J. Galen/SD4; Duane L. Pierson/SD4
Task Performed by: Johnson Space Center
Krug International, NAS9-17720

MS 14 **Water System Test Bed Support Long Duration Space Flight**
Funded by: Life Sciences (UPN 199)
Principal Investigators: J. Schultz/SD4; D. Flanagan/SD4; R. Gibbons/SD4; H. Brown/SD4 R. Taylor/SD4; R. Sauer/SD4; D. Pierson/SD4
Task Performed by: Johnson Space Center
Krug International, NAS9-17720

MS 15 **Determination of Residual Carbon Dioxide During Forced Ventilation of a Hemispherical Space Suit Helmet**
Funded by: Life Sciences (UPN 199)
Principal Investigators: John Gilbert, III/KI; Susan Schentrup/EC3
Task Performed by: Krug International, NAS9-17720

**MS 16** **In Vitro Three Dimensional Tissue Modeling**
Funded by: Microgravity (UPN 694)
Principal Investigators: T. Goodwin/SD4; J. M. Jessup;
C. Sams/SD4; D. Wolf/SD4
Task Performed by: Johnson Space Center
Krug International, NAS9-17720
University of Texas, M. D. Anderson Cancer Center

**MS 17** **Flow Cytometric Analysis of Peptide Hormone Receptor Regulation on Circulating Human Monocytes and Lymphocytes**
Funded by: Life Sciences (UPN 199)
Principal Investigators: R. Meehan/UTMB; N. Cintron/SD4;
Charles Stewart/UTMB; L. Neale/SD4;
E. Kraus/SD4; M. Smith/UTMB
Task Performed by: Johnson Space Center
Krug International, NAS9-17720
University of Texas Medical Branch, Galveston, TX

**MS 18** **Gaseous Sterilization of Bioreactors**
Funded by: Microgravity (N 694)
Principal Investigator: J. Cross/SD4; R. Schwartz/SD4; D. Wolf/SD4
Task Performed by: Johnson Space Center
Krug International, NAS9-17720

**MS 19** **Infrared Physiological Data Link**
Funded by: Technology Utilization (UPN 141)
Principal Investigator: K. Dekome/EE6
Task Performed by: Lockheed Engineering and Science Co., NAS9-17900
Subcontracted to Wilton Industries

**MS 20** **Medical Considerations in the Design of a Crew Emergency Return Vehicle**
Funded by: Life Sciences (UPN 199)
Principal Investigators: J. Boyce/SD2
Task Performed by: Johnson Space Center
Wright State University, NAG9-263

**MS 21** **Mode A Preflight Adaptation Trainer**
Funded by: Life Sciences (UPN 199); OSF
Principal Investigators: Donald E. Parker
Task Performed by: Johnson Space Center
Miami University, NAS9-17413

# REPORT DOCUMENTATION PAGE

| | | |
|---|---|---|
| 1. Report No.<br>NASA TM-100 473 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Research and Technology<br>1988 Annual Report of the Lyndon Johnson Space Center | | 5. Report Date<br>March 1989 |
| | | 6. Performing Organization Code |
| 7. Author(s) | | 8. Performing Organization Report No.<br>S-590 |
| 9. Performing Organization Name and Address<br>Lyndon B. Johnson Space Center<br>Houston, Texas 77058 | | 10. Work Unit No.<br>992-15-00-00-72 |
| | | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address<br>National Aeronautics and Space Administration<br>Washington, D.C. 20546 | | 13. Type of Report and Period Covered<br>Technical Memorandum |
| | | 14. Sponsoring Agency Code |

15. Supplementary Notes

16. Abstract
Johnson Space Center accomplishments in new and advanced concepts during 1988 are highlighted. This year, reports are grouped in sections Space System Technology, Solar System Sciences, Space Transportation Technology, and Medical Sciences. Summmary sections describing the role of Johnson Space Center in each program are followec by descriptions of significant tasks. Descriptions are suitable for external consumption, free of technical jargon, and illustrated to increase ease of comprehension.

| | |
|---|---|
| 17. Key Words (Suggested by Author(s))<br>Research and Technology<br>R&T<br>RTOP<br>Advanced Programs | 18. Distribution Statement<br>Unclassified-Unlimited<br><br>Subject Category: 99 |

| | | | |
|---|---|---|---|
| 19. Security Classification (of this report)<br>Unclassified | 20 Security Classification (of this page)<br>Unclassified | 21. No. of pages<br>181 | 22 Price |